



Technical Report SL-97-13  
November 1997

## Soil-Embedded and Oil-Immersed Soil Stress Gage Calibration Tests

by Walton C. Dickson, Jon E. Windham

19971215 138

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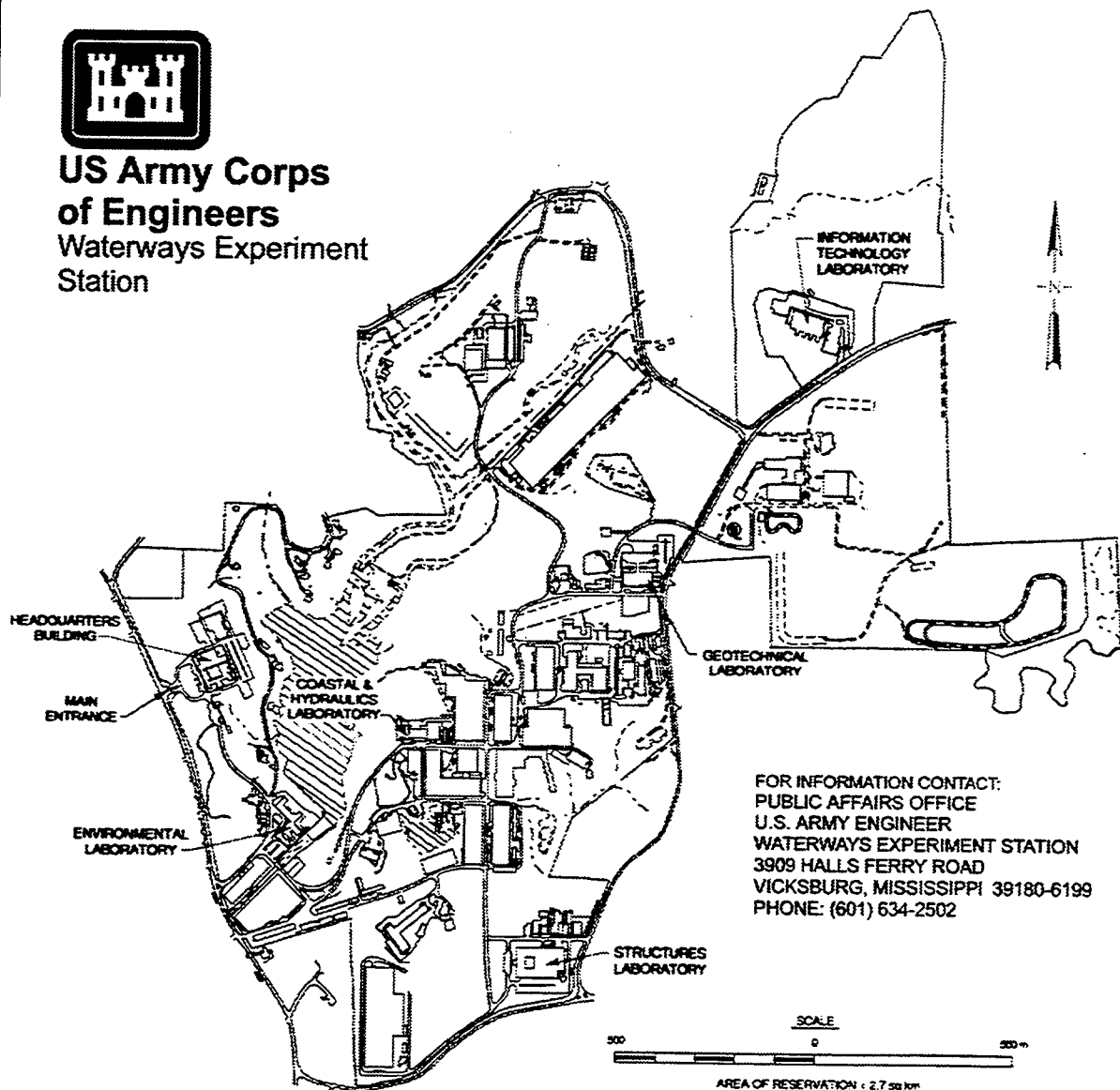
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Prepared for Defense Special Weapons Agency  
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of Engineers**  
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**Waterways Experiment Station Cataloging-in-Publication Data**

Dickson, Walton C.

Soil-embedded and oil-immersed soil stress gage calibration tests / by Walton C. Dickson, Jon E. Windham ; prepared for Defense Special Weapons Agency.

322 p. : ill. ; 28 cm. — (Technical report ; SL-97-13)

Includes bibliographical references.

1. Strain gages — Calibration. 2. Stress concentration — Measurement. 3. Explosives. 4. Blast effect — Measurement. I. Windham, Jon E. (Jon Enrique) II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Structures Laboratory (U.S. Army Engineer Waterways Experiment Station) V. United States. Defense Special Weapons Agency. VI. Title. VII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; SL-97-13.  
TA7 W34 no.SL-97-13

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# Preface

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The U.S. Army Engineer Waterways Experiment Station (WES) was tasked by the Defense Special Weapons Agency to research the factors affecting the measurement of stress in soil backfills during high-explosive test events. Laboratory calibration tests were conducted on soil stress gages embedded in flume sand, Yuma clayey sand, and Vicksburg loess (silty clay). Comparison tests were conducted on gages immersed in oil. This report documents the results of these tests. The work was funded by DSWA under Task Code RSRB, FY85 and FY86 Work Unit 00058, (Task 3): "In Situ Backfill Property Tests."

Responsibility for coordinating the overall program was assigned to Dr. Jon E. Windham, Geomechanics and Explosion Effects Division (GEED), Structures Laboratory (SL). The soil-embedded calibration tests were performed in the GEED Geodynamics Test Facility; the oil-immersed tests were conducted by the WES Instrumentation Services Division, Information Technology Laboratory. This report was prepared by Mr. Walton C. Dickson and Dr. Jon E. Windham, GEED. Dr. Jimmy P. Balsara was Chief, GEED, and Mr. Bryant Mather was Director, SL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

# Conversion Factors, Non-SI to SI Units of Measurement

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Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

# 1 Introduction

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## Background

The U.S. Army Engineer Waterways Experiment Station (WES) has conducted high-explosive (HE) field tests for many years. Soil stress measurements are used to determine or deduce many aspects of an HE test, hence, accurate calibration of soil stress gages is essential to proper interpretation of a test event. WES has typically calibrated the soil stress gages used in HE field tests hydrostatically (Ahmad 1985). The result of a hydrostatic calibration is linear for loading and unloading. Therefore, a one-step linear calibration has been used to convert the voltage output of a soil stress gage to a pressure. Unfortunately, soils do not typically behave as linear elastic materials. To the contrary, soil stress-strain behavior is usually nonlinear and hysteretic. Therefore, a calibration technique is needed to convert the voltage output of a soil stress gage to a pressure based upon the soil backfill material in which the gage is embedded.

WES was tasked by the Defense Special Weapons Agency (DSWA) to develop a technique to reduce field voltage records to stress records that accounts for the nonlinear-hysteretic response of soils. To accomplish this task, low-range and high-range soil stress gages were calibrated hydrostatically and also calibrated in three different soils. The output from some of these tests were measured in volts. Calibration tests were also conducted in which strain from each of the strain gages in the stress gages' sensing bridge circuit was directly recorded as output; the results of these tests can be compared with results from finite element gage-simulation calculations.

## Purpose and Scope

The purpose of this report is to document the results of the calibration tests conducted on soil stress gages. A description of the soils used, the test equipment, and the test procedures are presented in Chapter 2. Results from the calibration tests are presented and compared in Chapter 3. Chapter 4 contains a summary.



## 2 Calibration Tests

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Calibration tests were conducted on both low-range (to 30 MPa) and high-range (to 70 MPa) diaphragm-type soil stress gages, denoted LRSE and HRSE, respectively. Each type of gage was calibrated hydrostatically (immersed in oil) and also while embedded in three different soil backfill materials, i.e., flume sand, Yuma clayey sand, and Vicksburg loess (silty clay).

### Soil Descriptions

Laboratory test programs have previously been documented for all three soils used in the soil-embedded gage calibrations. A summary of the classification and mechanical property test results for each soil type follows.

#### Flume sand

Laboratory test results for flume sand are well documented (Green 1986a). Flume sand is a light brown sand that classifies as SP using the Unified Soil Classification System (USCS) (U.S. Army Engineer Waterways Experiment Station 1960). A typical gradation curve for flume sand is shown on Figure 2.1; the specific gravity of flume sand is 2.64. Flume sand has a maximum dry density of 1.80 Mg/m<sup>3</sup> (112.3 pcf) and a minimum dry density of 1.50 Mg/m<sup>3</sup> (93.6 pcf). Target composition property values for the soil-embedded calibration tests were 1.62 Mg/m<sup>3</sup> (101.0 pcf) dry density and 5.0 percent water content. The uniaxial strain (UX) stress-strain relationship and the UX stress path for flume sand are shown on Figure 2.2.

#### Yuma clayey sand

Laboratory test results for Yuma clayey sand are also well documented (Cargile 1986). Yuma clayey sand is a reddish-brown material with a USCS classification of SC. A typical gradation curve for this material is shown on Figure 2.3. This material has a liquid limit (LL) of 48 and a plastic limit (PL) of 17; the specific gravity of Yuma clayey sand is 2.68. Compaction tests yielded a

standard proctor dry density of 1.95 Mg/m<sup>3</sup> (121.7 pcf) at an optimum water content of 11.6 percent and a modified proctor maximum dry density of 2.11 Mg/m<sup>3</sup> (131.7 pcf) at a optimum water content of 7.9 percent. Target values of dry density and water content for the calibration test samples were 1.84 Mg/m<sup>3</sup> (115.0 pcf) and 3.0 percent, respectively. The corresponding UX stress-strain relationship and UX stress path for Yuma clayey sand are shown on Figure 2.4.

### Vicksburg loess (silty clay)

The material properties of this soil have been documented (Green 1986b). Vicksburg loess is a brownish soil that classifies as a silty clay (CL) using USCS. A typical gradation curve for this material is shown on Figure 2.5. Atterberg limits tests indicated a LL of 32 and a PL of 20. This silty clay has a specific gravity of 2.71. Compaction tests yielded a standard proctor maximum dry density of 1.72 Mg/m<sup>3</sup> (107.1 pcf) at an optimum water content of 16.2 percent and modified proctor maximum density of 1.84 Mg/m<sup>3</sup> (114.7 pcf) with an optimum water content of 13.7 percent. Shown on Figure 2.6 is the UX compressibility relationship and UX stress path for Vicksburg loess at the target dry density of 1.62 Mg/m<sup>3</sup> (101.0 pcf) and the target water content of 11.9 percent.

## Soil Stress Gages

Two SE-type soil stress gages were used in the calibration tests, i.e., LRSE and HRSE gages. Both gages are manufactured by Kulite Semiconductor Products, Inc.

The LRSE gage is Kulite model no. LQ-080U with a range of 0 to 30 MPa; its design is well documented (Ingram 1967 and Ingram 1968). The gage is 0.225-in. thick and 1.20 in. in diameter. The active gage sensor consists of four strain gages attached to the diaphragms as shown on Figure 2.7. The gages are located so that the stress gage measures a single scalar response equal to the sum of the four strain gages, i.e.,

$$\epsilon_{\text{TOTAL}} = \epsilon_{\text{TOP CENTER}} - \epsilon_{\text{TOP EDGE}} + \epsilon_{\text{BOTTOM CENTER}} - \epsilon_{\text{BOTTOM EDGE}}$$

The gage is usually placed in an confining ring, shown on Figure 2.8, to prevent lateral loads from affecting the readings. A small annulus of RTV silicone rubber adhesive sealant is placed between the gage and the confining ring. This material significantly reduces the lateral load transfer into the gage.

The HRSE gage is Kulite model no. LQV-080-8U with a range from 0 to 70 MPa. The HRSE is basically a LRSE gage but with diaphragms that are twice as thick as the ones used in the LRSE gage (Welch 1982). A confining ring is used to reduce lateral loads and to increase the effective diameter of the gage. Again, RTV silicone rubber adhesive sealant is placed between the gage and the confining

ring. Figure 2.9 presents a cross-sectional view of the HRSE gage in its confining ring, and Figure 2.10 shows the plan view of the gage and confining ring.

## General Calibration Procedures

The calibration of a gage consists of two parts (Denise 1987). The first part is electrical and consists of shunting a series of known resistors across a bridge circuit and measuring the voltage output. The result is the determination of the overall electrical resistance of the gage,  $R_g$ , and a factor,  $K$ , related to the gain used on the amplifier during that particular calibration.

The second part of the calibration is physical, in which a known stress is applied to the face of the gage and its electrical response is measured in terms of amplified voltage. The slope of the amplified voltage versus pressure curve is denoted as  $S$ . When this slope is multiplied by the  $K$  factor found in the electrical calibration, the product is the calibration constant of the gage,  $C_a$ .

Multiplying by the  $K$  factors is a normalization process, allowing the slopes of several different calibration curves to be compared even if the gain on the amplifier was different (i.e., different values of  $K$ ). The end result is the same if the raw voltage data is first divided by  $K$ , and then the slope,  $S$ , is determined. In this way, different calibrations can be compared using numerical models other than a straight line.

## Oil-Immersed Calibration Tests

Details of test equipment and procedures used by WES to conduct hydrostatic calibrations have been documented (Ahmad 1985). As listed in Table 2.1, 70 oil-immersed calibration tests were conducted in this study. Results from standard tests in which voltage output from the full bridge was measured for LRSE gages are shown on PLATES 1-13. Six LRSE gages were calibrated one time; an additional gage was calibrated seven times. Eleven HRSE gages were calibrated one time each and two gages were calibrated seven times each. The results of these calibration tests are displayed on PLATES 14-38.

In addition to the standard WES hydrostatic calibrations, tests were conducted in which strain from the individual strain gages in the bridge was directly recorded as output. Nomenclature for the individual strain gages is presented on Figure 2.11. The calibration tests were conducted in the same manner as the standard calibration test. Two LRSE gages were calibrated in this manner, as shown on PLATES 39-46. Two HRSE gages in which the individual strain gage measurements were recorded were calibrated three times each; results from these tests are given on PLATES 47-70.

## Soil-Embedded Calibration Tests

Calibration tests were run with the stress gages embedded in compacted soil backfill specimens for comparison with the hydrostatic calibrations. Again, there was an electrical and a physical part to the calibration. The test device used for soil-embedded gage calibrations is shown in Figure 2.12. The wafer-shaped soil specimen was constructed by rodding the soil into the test chamber until it was half full. A soil stress gage was placed in the chamber, and then soil was rodded into the chamber until the sample was flush with the top of the base. A rubber membrane was placed over the sample, and hydraulic pressure was applied statically to the membrane and hence to the sample. The applied pressure and the resulting output (voltage or strain) from the embedded gage were recorded manually. The 187 soil-embedded calibrations listed in Table 2.2 included loading, unloading, and reloading cycles (see PLATES 71-257).

Calibration tests with voltage output were conducted on both LRSE and HRSE gages in flume sand. For both LRSE and HRSE gages, six gages were calibrated one time each and one gage was calibrated six times. The results of these 24 soil-embedded calibrations in flume sand are shown on PLATES 71-94. Flume sand-embedded calibration tests were also conducted with strain from each of the four strain gages in the wheatstone bridges of the LRSE or HRSE gages recorded directly. The strain output tests were conducted with the LRSE gages oriented in four ways as shown in Figure 2.13:

- a. Vertical measurement without confining ring.
- b. Vertical measurement with confining ring.
- c. Horizontal measurement without confining ring.
- d. Horizontal measurement with confining ring.

Strain output tests were conducted with the HRSE gage in two orientations as shown in Figure 2.14:

- a. Vertical measurement without confining ring.
- b. Vertical measurement with confining ring.

Two LRSE gages were tested and each gage was calibrated three times in the four orientations (see PLATES 95-190). Only one HRSE gage was calibrated in this manner. The data for the three calibration tests in each configuration of the HRSE gage are documented on PLATES 191-214.

The results of 12 LRSE and 12 HRSE gage calibration tests in Yuma clayey sand are given on PLATES 215-238. All tests were conducted with voltage as the measured output. For both the LRSE and the HRSE series, six gages were calibrated one time each and one gage was calibrated six times.

Only 19 soil-embedded tests were conducted in Vicksburg loess (silty clay); all were conducted with voltage as the output variable. Nine of these tests were conducted using LRSE gages; six gages were tested one time each and one gage was tested three times (see PLATES 239-247). A total of 10 silty clay-embedded calibration tests were conducted using HRSE gages. Again, six gages were calibrated one time each, and one gage was calibrated four times (see PLATES 248-257).

Table 2.1

## Oil-Immersed Calibration Tests

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant (Ca)	Strain Gage Recorded
1	LRSE	6-3955-84	No	Hydraulic Oil/1	NA	Volts	0.25615	6.37123	2980.2	Full Bridge
2	LRSE	2-3692-84	No	Hydraulic Oil/1	NA	Volts	0.26055	6.52000	3170.3	Full Bridge
3	LRSE	2-3694-84	No	Hydraulic Oil/1	NA	Volts	0.25722	6.41587	3161.8	Full Bridge
4	LRSE	2-3703-84	No	Hydraulic Oil/1	NA	Volts	0.26892	7.00787	3497.3	Full Bridge
5	LRSE	2-3710-84	No	Hydraulic Oil/1	NA	Volts	0.25885	6.42937	3251.8	Full Bridge
6	LRSE	9-3603-83	No	Hydraulic Oil/1	NA	Volts	0.26927	6.92773	3528.0	Full Bridge
7	LRSE	9-3611-83	No	Hydraulic Oil/1	NA	Volts	0.27614	7.37281	3670.1	Full Bridge
8	LRSE	2-3710-84	No	Hydraulic Oil/1	NA	Volts	0.26717	6.28817	3470.3	Full Bridge
9	LRSE	2-3710-84	No	Hydraulic Oil/2	NA	Volts	0.26717	6.28817	3479.6	Full Bridge
10	LRSE	2-3710-84	No	Hydraulic Oil/3	NA	Volts	0.26717	6.28817	3400.5	Full Bridge
11	LRSE	2-3710-84	No	Hydraulic Oil/4	NA	Volts	0.26717	6.28817	3481.3	Full Bridge
12	LRSE	2-3710-84	No	Hydraulic Oil/5	NA	Volts	0.26717	6.28817	3456.8	Full Bridge
13	LRSE	2-3710-84	No	Hydraulic Oil/6	NA	Volts	0.26717	6.28817	3476.7	Full Bridge
14	HRSE	9-3968-84	No	Hydraulic Oil/1	NA	Volts	0.28987	10.44767	15629.5	Full Bridge
15	HRSE	8-3940-84	No	Hydraulic Oil/1	NA	Volts	0.26191	8.49026	14988.5	Full Bridge
16	HRSE	8-3941-84	No	Hydraulic Oil/1	NA	Volts	0.26332	8.63506	14287.2	Full Bridge
17	HRSE	8-3951-84	No	Hydraulic Oil/1	NA	Volts	0.28748	10.20199	16100.2	Full Bridge
18	HRSE	10-3633-83	No	Hydraulic Oil/1	NA	volts	0.24982	5.97530	13298.0	Full Bridge

(Sheet 1 of 4)

Table 2.1 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant ( $C_a$ )	Strain Gage Recorded
19	HRSE	10-3627-83	No	Hydraulic Oil/1	NA	Volts	0.24875	5.92350	11981.0	Full Bridge
20	HRSE	10-3630-83	No	Hydraulic Oil/1	NA	Volts	0.25079	6.07781	13540.6	Full Bridge
21	HRSE	6-3515-83	No	Hydraulic Oil/1	NA	Volts	0.26420	6.75134	12790.5	Full Bridge
22	HRSE	6-3518-83	No	Hydraulic Oil/1	NA	Volts	0.26503	6.81003	12143.1	Full Bridge
23	HRSE	10-3620-83	No	Hydraulic Oil/1	NA	Volts	0.24814	5.90426	12242.8	Full Bridge
24	HRSE	10-3623-83	No	Hydraulic Oil/1	NA	Volts	0.25295	6.18042	11633.5	Full Bridge
25	HRSE	10-3625-83	No	Hydraulic Oil/1	NA	Volts	0.25170	6.03678	12566.7	Full Bridge
26	HRSE	8-3940-84	No	Hydraulic Oil/1	NA	Volts	0.28324	9.83134	15028.6	Full Bridge
27	HRSE	8-3940-84	No	Hydraulic Oil/2	NA	Volts	0.28324	9.83134	15120.6	Full Bridge
28	HRSE	8-3940-84	No	Hydraulic Oil/3	NA	Volts	0.28324	9.83134	15113.0	Full Bridge
29	HRSE	8-3940-84	No	Hydraulic Oil/4	NA	Volts	0.28324	9.83134	15065.3	Full Bridge
30	HRSE	8-3940-84	No	Hydraulic Oil/5	NA	Volts	0.28324	9.83134	15116.4	Full Bridge
31	HRSE	8-3940-84	No	Hydraulic Oil/6	NA	Volts	0.28324	9.83134	15123.5	Full Bridge
32	HRSE	10-4000-84	No	Hydraulic Oil/1	NA	Volts	0.29089	10.64859	14023.5	Full Bridge
33	HRSE	10-4000-84	No	Hydraulic Oil/2	NA	Volts	0.29089	10.64859	14039.5	Full Bridge
34	HRSE	10-4000-84	No	Hydraulic Oil/3	NA	Volts	0.29089	10.64859	14080.3	Full Bridge
35	HRSE	10-4000-84	No	Hydraulic Oil/4	NA	Volts	0.29089	10.64859	14109.1	Full Bridge
36	HRSE	10-4000-84	No	Hydraulic Oil/5	NA	Volts	0.29089	10.64859	14153.0	Full Bridge
37	HRSE	10-4000-84	No	Hydraulic Oil/6	NA	Volts	0.29089	10.64859	14148.9	Full Bridge

(Sheet 2 of 4)

Table 2.1 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant (Ca)	Strain Gage Recorded
38	HRSE	10-4000-84	No	Hydraulic Oil/1	NA	Volts	0.23633	8.94404	13893.9	Full Bridge
39	LRSE	2-3694-84	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Edge
40	LRSE	2-3694-84	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Edge
41	LRSE	2-3694-84	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Center
42	LRSE	2-3694-84	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Center
43	LRSE	9-3601-83	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Edge
44	LRSE	9-3601-83	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Edge
45	LRSE	9-3601-83	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Center
46	LRSE	9-3601-83	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Center
47	HRSE	2	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Edge
48	HRSE	2	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Edge
49	HRSE	2	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Center
50	HRSE	2	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Center
51	HRSE	2	No	Hydraulic Oil/2	NA	Strain	—	—	—	Top Edge
52	HRSE	2	No	Hydraulic Oil/2	NA	Strain	—	—	—	Bottom Edge
53	HRSE	2	No	Hydraulic Oil/2	NA	Strain	—	—	—	Bottom Center
54	HRSE	2	No	Hydraulic Oil/2	NA	Strain	—	—	—	Top Center

(Sheet 3 of 4)



Table 2.1 (Concluded)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor ( $K$ )	Calibration Constant ( $C_a$ )	Strain Gage Recorded
55	HRSE	2	No	Hydraulic Oil/3	NA	Strain	—	—	—	Top Edge
56	HRSE	2	No	Hydraulic Oil/3	NA	Strain	—	—	—	Bottom Edge
57	HRSE	2	No	Hydraulic Oil/3	NA	Strain	—	—	—	Bottom Center
58	HRSE	2	No	Hydraulic Oil/3	NA	Strain	—	—	—	Top Center
59	HRSE	1	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Edge
60	HRSE	1	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Edge
61	HRSE	1	No	Hydraulic Oil/1	NA	Strain	—	—	—	Bottom Center
62	HRSE	1	No	Hydraulic Oil/1	NA	Strain	—	—	—	Top Center
63	HRSE	1	No	Hydraulic Oil/2	NA	Strain	—	—	—	Top Edge
64	HRSE	1	No	Hydraulic Oil/2	NA	Strain	—	—	—	Bottom Edge
65	HRSE	1	No	Hydraulic Oil/2	NA	Strain	—	—	—	Bottom Center
66	HRSE	1	No	Hydraulic Oil/2	NA	Strain	—	—	—	Top Center
67	HRSE	1	No	Hydraulic Oil/3	NA	Strain	—	—	—	Top Edge
68	HRSE	1	No	Hydraulic Oil/3	NA	Strain	—	—	—	Bottom Edge
69	HRSE	1	No	Hydraulic Oil/3	NA	Strain	—	—	—	Bottom Center
70	HRSE	1	No	Hydraulic Oil/3	NA	Strain	—	—	—	Top Center

(Sheet 4 of 4)

Table 2.2

## Soil-Embedded Calibration Tests

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant (Ca)	Strain Gage Recorded
71	LRSE	2-3703-84	No	Flume Sand/1	Vert	Volts	0.25781	6.92262	3466.0	Full Bridge
72	LRSE	2-3694-84	No	Flume Sand/1	Vert	Volts	0.24897	6.37263	2880.0	Full Bridge
73	LRSE	9-3611-83	No	Flume Sand/1	Vert	Volts	0.26559	7.28432	3551.1	Full Bridge
74	LRSE	2-3692-84	No	Flume Sand/1	Vert	Volts	0.25131	6.47099	2949.7	Full Bridge
75	LRSE	9-3603-83	No	Flume Sand/1	Vert	Volts	0.26764	6.43072	3099.3	Full Bridge
76	LRSE	2-3710-84	No	Flume Sand/1	Vert	Volts	0.24976	6.34108	3211.5	Full Bridge
77	LRSE	6-3955-84	No	Flume Sand/1	Vert	Volts	0.24787	6.39372	2892.7	Full Bridge
78	LRSE	6-3955-84	No	Flume Sand/2	Vert	Volts	0.23876	6.39566	2927.7	Full Bridge
79	LRSE	6-3955-84	No	Flume Sand/3	Vert	Volts	0.24631	6.39577	2978.3	Full Bridge
80	LRSE	6-3955-84	No	Flume Sand/4	Vert	Volts	0.24850	6.40265	3279.6	Full Bridge
81	LRSE	6-3955-84	No	Flume Sand/5	Vert	Volts	0.24848	6.40343	2974.1	Full Bridge
82	LRSE	6-3955-84	No	Flume Sand/6	Vert	Volts	0.24561	6.38175	3044.2	Full Bridge
83	HRSE	8-3951-84	No	Flume Sand/1	Vert	Volts	0.29322	6.49645	15636.8	Full Bridge
84	HRSE	9-3968-84	No	Flume Sand/1	Vert	Volts	0.29303	6.43369	14837.1	Full Bridge
85	HRSE	8-3941-84	No	Flume Sand/1	Vert	Volts	0.26860	6.35327	13209.6	Full Bridge
86	HRSE	10-3625-83	No	Flume Sand/1	Vert	Volts	0.24239	6.21974	11157.5	Full Bridge
87	HRSE	6-3515-83	No	Flume Sand/1	Vert	Volts	0.25498	6.32088	11777.6	Full Bridge

(Sheet 1 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant ( $C_e$ )	Strain Gage Recorded
88	HRSE	10-3630-83	No	Flume Sand/1	Vert	Volts	0.23996	6.14889	12306.5	Full Bridge
89	HRSE	10-4000-84	No	Flume Sand/1	Vert	Volts	0.27192	6.37687	12914.1	Full Bridge
90	HRSE	10-4000-84	No	Flume Sand/2	Vert	Volts	0.27171	6.36729	12800.0	Full Bridge
91	HRSE	10-4000-84	No	Flume Sand/3	Vert	Volts	0.27130	6.35603	13198.3	Full Bridge
92	HRSE	10-4000-84	No	Flume Sand/4	Vert	Volts	0.27075	6.34230	13335.5	Full Bridge
93	HRSE	10-4000-84	No	Flume Sand/5	Vert	Volts	0.27176	6.35701	12961.6	Full Bridge
94	HRSE	10-4000-84	No	Flume Sand/6	Vert	Volts	0.27025	6.32981	12739.5	Full Bridge
95	LRSE	2-3694-84	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
96	LRSE	2-3694-84	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Center
97	LRSE	2-3694-84	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge
98	LRSE	2-3694-84	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Edge
99	LRSE	2-3694-84	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
100	LRSE	2-3694-84	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Center
101	LRSE	2-3694-84	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Edge
102	LRSE	2-3694-84	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
103	LRSE	2-3694-84	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center
104	LRSE	2-3694-84	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Center

(Sheet 2 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor ( $K$ )	Calibration Constant ( $C_a$ )	Strain Gage Recorded
105	LRSE	2-3694-84	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
106	LRSE	2-3694-84	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
107	LRSE	9-3601-83	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
108	LRSE	9-3601-83	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Center
109	LRSE	9-3601-83	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge
110	LRSE	9-3601-83	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Edge
111	LRSE	9-3601-83	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
112	LRSE	9-3601-83	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Center
113	LRSE	9-3601-83	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Edge
114	LRSE	9-3601-83	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
115	LRSE	9-3601-83	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center
116	LRSE	9-3601-83	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Center
117	LRSE	9-3601-83	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
118	LRSE	9-3601-83	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
119	LRSE	2-3694-84	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
120	LRSE	2-3694-84	No	Flume Sand/1	Vert	Strain	—	—	—	Top Center
121	LRSE	2-3694-84	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge
122	LRSE	2-3694-84	No	Flume Sand/1	Vert	Strain	—	—	—	Top Edge

(Sheet 3 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant (Ca)	Strain Gage Recorded
123	LRSE	2-3694-84	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
124	LRSE	2-3694-84	No	Flume Sand/2	Vert	Strain	—	—	—	Top Center
125	LRSE	2-3694-84	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Edge
126	LRSE	2-3694-84	No	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
127	LRSE	2-3694-84	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center
128	LRSE	2-3694-84	No	Flume Sand/3	Vert	Strain	—	—	—	Top Center
129	LRSE	2-3694-84	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
130	LRSE	2-3694-84	No	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
131	LRSE	9-3601-83	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
132	LRSE	9-3601-83	No	Flume Sand/1	Vert	Strain	—	—	—	Top Center
133	LRSE	9-3601-83	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge
134	LRSE	9-3601-83	No	Flume Sand/1	Vert	Strain	—	—	—	Top Edge
135	LRSE	9-3601-83	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
136	LRSE	9-3601-83	No	Flume Sand/2	Vert	Strain	—	—	—	Top Center
137	LRSE	9-3601-83	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
138	LRSE	9-3601-83	No	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
139	LRSE	9-3601-83	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center
140	LRSE	9-3601-83	No	Flume Sand/3	Vert	Strain	—	—	—	Top Center

(Sheet 4 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant ( $C_a$ )	Strain Gage Recorded
141	LRSE	9-3601-83	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
142	LRSE	9-3601-83	No	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
143	LRSE	2-3694-84	Yes	Flume Sand/1	Hor	Strain	—	—	—	Bottom Center
144	LRSE	2-3694-84	Yes	Flume Sand/1	Hor	Strain	—	—	—	Top Center
145	LRSE	2-3694-84	Yes	Flume Sand/1	Hor	Strain	—	—	—	Bottom Edge
146	LRSE	2-3694-84	Yes	Flume Sand/1	Hor	Strain	—	—	—	Top Edge
147	LRSE	2-3694-84	Yes	Flume Sand/2	Hor	Strain	—	—	—	Bottom Center
148	LRSE	2-3694-84	Yes	Flume Sand/2	Hor	Strain	—	—	—	Top Center
149	LRSE	2-3694-84	Yes	Flume Sand/2	Hor	Strain	—	—	—	Bottom Edge
150	LRSE	2-3694-84	Yes	Flume Sand/2	Hor	Strain	—	—	—	Top Edge
151	LRSE	2-3694-84	Yes	Flume Sand/3	Hor	Strain	—	—	—	Bottom Center
152	LRSE	2-3694-84	Yes	Flume Sand/3	Hor	Strain	—	—	—	Top Center
153	LRSE	2-3694-84	Yes	Flume Sand/3	Hor	Strain	—	—	—	Bottom Edge
154	LRSE	2-3694-84	Yes	Flume Sand/3	Hor	Strain	—	—	—	Top Edge
155	LRSE	9-3601-83	Yes	Flume Sand/1	Hor	Strain	—	—	—	Bottom Center
156	LRSE	9-3601-83	Yes	Flume Sand/1	Hor	Strain	—	—	—	Top Center
157	LRSE	9-3601-83	Yes	Flume Sand/1	Hor	Strain	—	—	—	Bottom Edge
158	LRSE	9-3601-83	Yes	Flume Sand/1	Hor	Strain	—	—	—	Top Edge

(Sheet 5 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor ( $K$ )	Calibration Constant (Ca)	Strain Gage Recorded
159	LRSE	9-3601-83	Yes	Flume Sand/2	Hor	Strain	—	—	—	Bottom Center
160	LRSE	9-3601-83	Yes	Flume Sand/2	Hor	Strain	—	—	—	Top Center
161	LRSE	9-3601-83	Yes	Flume Sand/2	Hor	Strain	—	—	—	Bottom Edge
162	LRSE	9-3601-83	Yes	Flume Sand/2	Hor	Strain	—	—	—	Top Edge
163	LRSE	9-3601-83	Yes	Flume Sand/3	Hor	Strain	—	—	—	Bottom Center
164	LRSE	9-3601-83	Yes	Flume Sand/3	Hor	Strain	—	—	—	Top Center
165	LRSE	9-3601-83	Yes	Flume Sand/3	Hor	Strain	—	—	—	Bottom Edge
166	LRSE	9-3601-83	Yes	Flume Sand/3	Hor	Strain	—	—	—	Top Edge
167	LRSE	2-3694-84	No	Flume Sand/1	Hor	Strain	—	—	—	Bottom Center
168	LRSE	2-3694-84	No	Flume Sand/1	Hor	Strain	—	—	—	Top Center
169	LRSE	2-3694-84	No	Flume Sand/1	Hor	Strain	—	—	—	Bottom Edge
170	LRSE	2-3694-84	No	Flume Sand/1	Hor	Strain	—	—	—	Top Edge
171	LRSE	2-3694-84	No	Flume Sand/2	Hor	Strain	—	—	—	Bottom Center
172	LRSE	2-3694-84	No	Flume Sand/2	Hor	Strain	—	—	—	Top Center
173	LRSE	2-3694-84	No	Flume Sand/2	Hor	Strain	—	—	—	Bottom Edge
174	LRSE	2-3694-84	No	Flume Sand/2	Hor	Strain	—	—	—	Top Edge
175	LRSE	2-3694-84	No	Flume Sand/3	Hor	Strain	—	—	—	Bottom Center
176	LRSE	2-3694-84	No	Flume Sand/3	Hor	Strain	—	—	—	Top Center

(Sheet 6 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant ( $C_a$ )	Strain Gage Recorded
177	LRSE	2-3694-84	No	Flume Sand/3	Hor	Strain	—	—	—	Bottom Edge
178	LRSE	2-3694-84	No	Flume Sand/3	Hor	Strain	—	—	—	Top Edge
179	LRSE	9-3601-83	No	Flume Sand/1	Hor	Strain	—	—	—	Bottom Center
180	LRSE	9-3601-83	No	Flume Sand/1	Hor	Strain	—	—	—	Top Center
181	LRSE	9-3601-83	No	Flume Sand/1	Hor	Strain	—	—	—	Bottom Edge
182	LRSE	9-3601-83	No	Flume Sand/1	Hor	Strain	—	—	—	Top Edge
183	LRSE	9-3601-83	No	Flume Sand/2	Hor	Strain	—	—	—	Bottom Center
184	LRSE	9-3601-83	No	Flume Sand/2	Hor	Strain	—	—	—	Top Center
185	LRSE	9-3601-83	No	Flume Sand/2	Hor	Strain	—	—	—	Bottom Edge
186	LRSE	9-3601-83	No	Flume Sand/2	Hor	Strain	—	—	—	Top Edge
187	LRSE	9-3601-83	No	Flume Sand/3	Hor	Strain	—	—	—	Bottom Center
188	LRSE	9-3601-83	No	Flume Sand/3	Hor	Strain	—	—	—	Top Center
189	LRSE	9-3601-83	No	Flume Sand/3	Hor	Strain	—	—	—	Bottom Edge
190	LRSE	9-3601-83	No	Flume Sand/3	Hor	Strain	—	—	—	Top Edge
191	HRSE	2	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
192	HRSE	2	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Center
193	HRSE	2	Yes	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge

(Sheet 7 of 11)



Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant ( $C_a$ )	Strain Gage Recorded
194	HRSE	2	Yes	Flume Sand/1	Vert	Strain	—	—	—	Top Edge
195	HRSE	2	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
196	HRSE	2	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Center
197	HRSE	2	Yes	Flume Sand/2	Vert	Strain	—	—	—	Bottom Edge
198	HRSE	2	Yes	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
199	HRSE	2	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center
200	HRSE	2	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Center
201	HRSE	2	Yes	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
202	HRSE	2	Yes	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
203	HRSE	2	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Center
204	HRSE	2	No	Flume Sand/1	Vert	Strain	—	—	—	Top Center
205	HRSE	2	No	Flume Sand/1	Vert	Strain	—	—	—	Bottom Edge
206	HRSE	2	No	Flume Sand/1	Vert	Strain	—	—	—	Top Edge
207	HRSE	2	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Center
208	HRSE	2	No	Flume Sand/2	Vert	Strain	—	—	—	Top Center
209	HRSE	2	No	Flume Sand/2	Vert	Strain	—	—	—	Bottom Edge
210	HRSE	2	No	Flume Sand/2	Vert	Strain	—	—	—	Top Edge
211	HRSE	2	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Center

(Sheet 8 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor ( $K$ )	Calibration Constant ( $C_a$ )	Strain Gage Recorded
212	HRSE	2	No	Flume Sand/3	Vert	Strain	—	—	—	Top Center
213	HRSE	2	No	Flume Sand/3	Vert	Strain	—	—	—	Bottom Edge
214	HRSE	2	No	Flume Sand/3	Vert	Strain	—	—	—	Top Edge
215	LRSE	2-3703-84	No	Clayey Sand/1	Vert	Volts	0.25751	6.92273	3446.4	Full Bridge
216	LRSE	2-3694-84	No	Clayey Sand/1	Vert	Volts	0.25004	6.37634	3173.5	Full Bridge
217	LRSE	9-3611-83	No	Clayey Sand/1	Vert	Volts	0.34320	7.65065	3106.2	Full Bridge
218	LRSE	2-3692-84	No	Clayey Sand/1	Vert	Volts	0.24957	6.46274	2715.9	Full Bridge
219	LRSE	9-3603-83	No	Clayey Sand/1	Vert	Volts	0.26692	7.40024	3057.2	Full Bridge
220	LRSE	2-3710-84	No	Clayey Sand/1	Vert	Volts	0.24710	6.36509	3113.7	Full Bridge
221	LRSE	6-3955-84	No	Clayey Sand/1	Vert	Volts	0.24725	6.41239	2766.4	Full Bridge
222	LRSE	6-3955-84	No	Clayey Sand/2	Vert	Volts	0.24660	6.38392	3009.1	Full Bridge
223	LRSE	6-3955-84	No	Clayey Sand/3	Vert	Volts	0.24735	6.41001	2771.1	Full Bridge
224	LRSE	6-3955-84	No	Clayey Sand/4	Vert	Volts	0.24570	6.40062	3109.3	Full Bridge
225	LRSE	6-3955-84	No	Clayey Sand/5	Vert	Volts	0.24436	6.39231	2848.0	Full Bridge
226	LRSE	6-3955-84	No	Clayey Sand/6	Vert	Volts	0.24757	6.28152	3048.1	Full Bridge
227	HRSE	8-3941-84	No	Clayey Sand/1	Vert	Volts	0.27050	6.43472	13923.2	Full Bridge

(Sheet 9 of 11)

Table 2.2 (Continued)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor (K)	Calibration Constant (Ca)	Strain Gage Recorded
228	HRSE	9-3968-84	No	Clayey Sand/1	Vert	Volts	0.29240	6.42579	13890.9	Full Bridge
229	HRSE	8-3951-84	No	Clayey Sand/1	Vert	Volts	0.29289	6.50550	12771.0	Full Bridge
230	HRSE	10-3625-83	No	Clayey Sand/1	Vert	Volts	0.24206	6.16446	11655.6	Full Bridge
231	HRSE	6-3515-83	No	Clayey Sand/1	Vert	Volts	0.25481	6.30138	9772.9	Full Bridge
232	HRSE	10-3630-83	No	Clayey Sand/1	Vert	Volts	0.23906	6.17753	9508.5	Full Bridge
233	HRSE	8-3940-84	No	Clayey Sand/1	Vert	Volts	0.26703	6.30191	14786.3	Full Bridge
234	HRSE	8-3940-84	No	Clayey Sand/2	Vert	Volts	0.26656	6.29288	18619.6	Full Bridge
235	HRSE	8-3940-84	No	Clayey Sand/3	Vert	Volts	0.26631	6.28848	10533.3	Full Bridge
236	HRSE	8-3940-84	No	Clayey Sand/4	Vert	Volts	0.26331	6.28057	9370.6	Full Bridge
237	HRSE	8-3940-84	No	Clayey Sand/5	Vert	Volts	0.26706	6.30902	10603.0	Full Bridge
238	HRSE	8-3940-84	No	Clayey Sand/6	Vert	Volts	0.26679	6.28786	10298.9	Full Bridge
239	LRSE	2-3703-84	No	Silty Clay/1	Vert	Volts	0.25447	6.91398	3150.1	Full Bridge
240	LRSE	2-3694-84	No	Silty Clay/1	Vert	Volts	0.24535	6.39791	2838.9	Full Bridge
241	LRSE	9-3611-83	No	Silty Clay/1	Vert	Volts	0.26203	7.28552	3170.3	Full Bridge
242	LRSE	2-3692-84	No	Silty Clay/1	Vert	Volts	0.24474	6.44172	2810.5	Full Bridge
243	LRSE	9-3603-83	No	Silty Clay/1	Vert	Volts	0.26321	6.41176	2881.9	Full Bridge
244	LRSE	2-3710-84	No	Silty Clay/1	Vert	Volts	0.24334	6.34741	2879.4	Full Bridge

(Sheet 10 of 11)

Table 2.2 (Concluded)

Plate Number	Gage Type	Serial Number	Confining Ring (Yes/No)	Calibration Medium/Run Number	Gage Orientation (Vert/Hor)	Output Measurement (Volts/Strain)	Gage Resistance ( $R_g$ )	Amplifier Gain Factor ( $K$ )	Calibration Constant ( $C_a$ )	Strain Gage Recorded
245	LRSE	6-3955-84	No	Silty Clay/1	Vert	Volts	0.24487	6.39000	2742.2	Full Bridge
246	LRSE	6-3955-84	No	Silty Clay/2	Vert	Volts	0.24498	6.38901	2592.8	Full Bridge
247	LRSE	6-3955-84	No	Silty Clay/3	Vert	Volts	0.24373	6.35841	2619.4	Full Bridge
248	HRSE	10-3623-83	No	Silty Clay/1	Vert	Volts	0.24034	6.19342	9935.4	Full Bridge
249	HRSE	10-3627-83	No	Silty Clay/1	Vert	Volts	0.23484	5.90089	9969.7	Full Bridge
250	HRSE	10-3625-83	No	Silty Clay/1	Vert	Volts	0.23841	6.05661	9996.6	Full Bridge
251	HRSE	10-3620-83	No	Silty Clay/1	Vert	Volts	0.23643	5.95133	8927.3	Full Bridge
252	HRSE	10-3630-83	No	Silty Clay/1	Vert	Volts	0.24103	6.08278	11584.9	Full Bridge
253	HRSE	6-3518-83	No	Silty Clay/1	Vert	Volts	0.24968	6.69804	12028.8	Full Bridge
254	HRSE	6-3515-83	No	Silty Clay/1	Vert	Volts	0.25091	6.68272	11348.3	Full Bridge
255	HRSE	10-3623-83	No	Silty Clay/1	Vert	Volts	0.23604	6.12567	9912.9	Full Bridge
256	HRSE	10-3623-83	No	Silty Clay/2	Vert	Volts	0.23746	6.18808	9542.6	Full Bridge
257	HRSE	10-3623-83	No	Silty Clay/3	Vert	Volts	0.24082	6.17389	9223.1	Full Bridge

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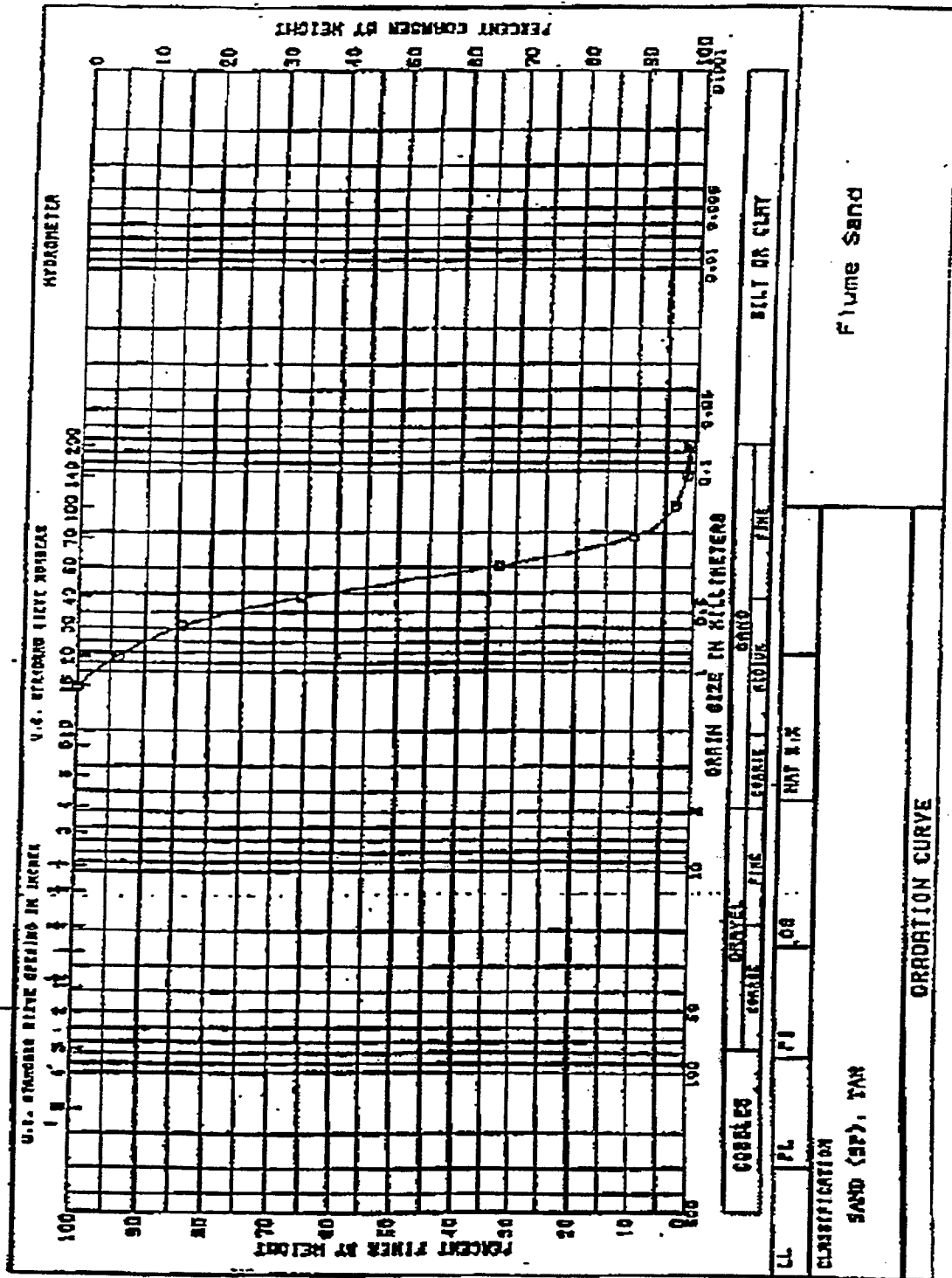


Figure 2.1. Typical grain-size distribution for flume sand

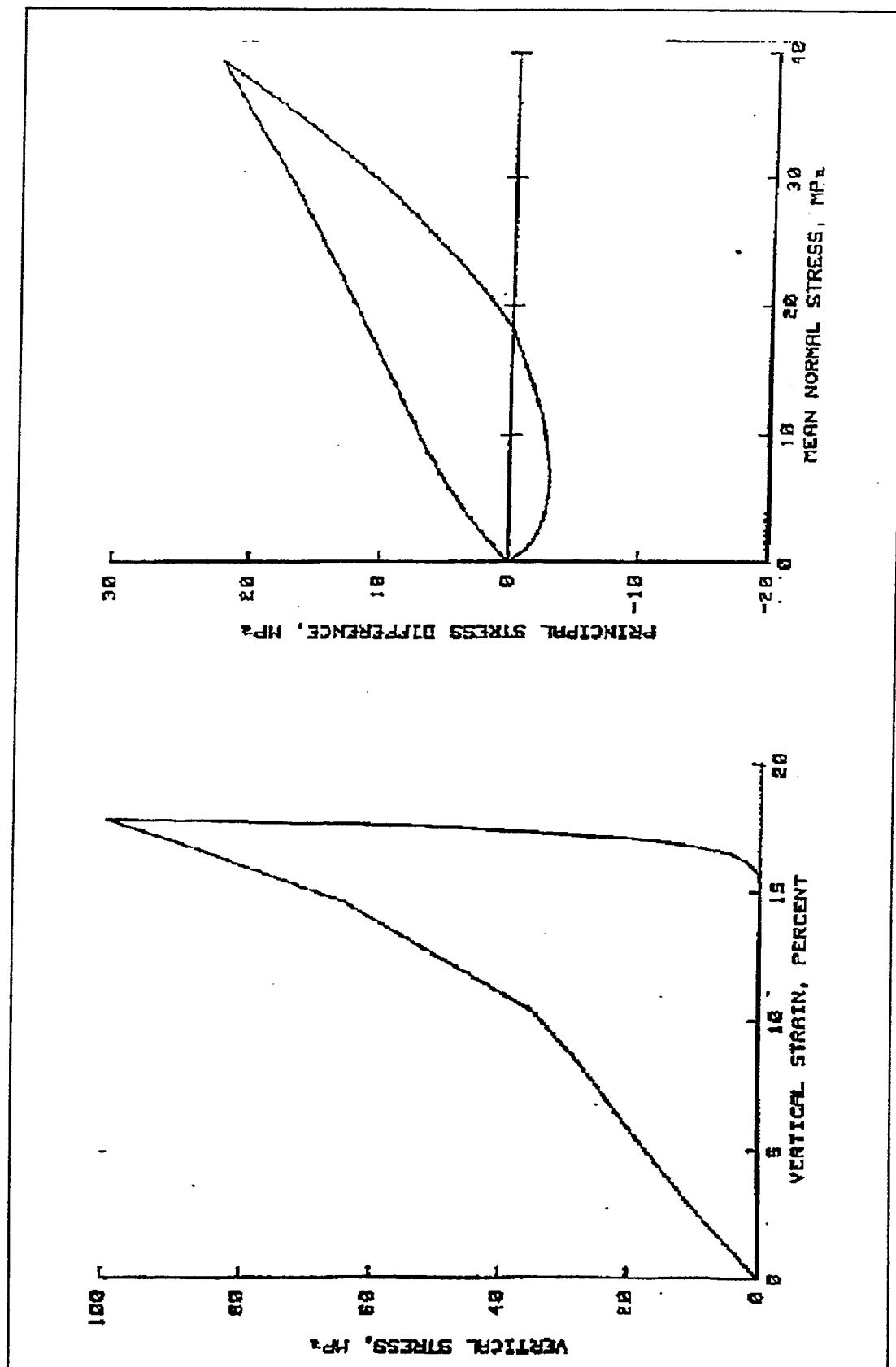


Figure 2.2. UX stress-strain relation and UX stress path for flume sand with  $\gamma_d = 1.62 \text{ Mg/m}^3$  and  $w = 5.0$  percent



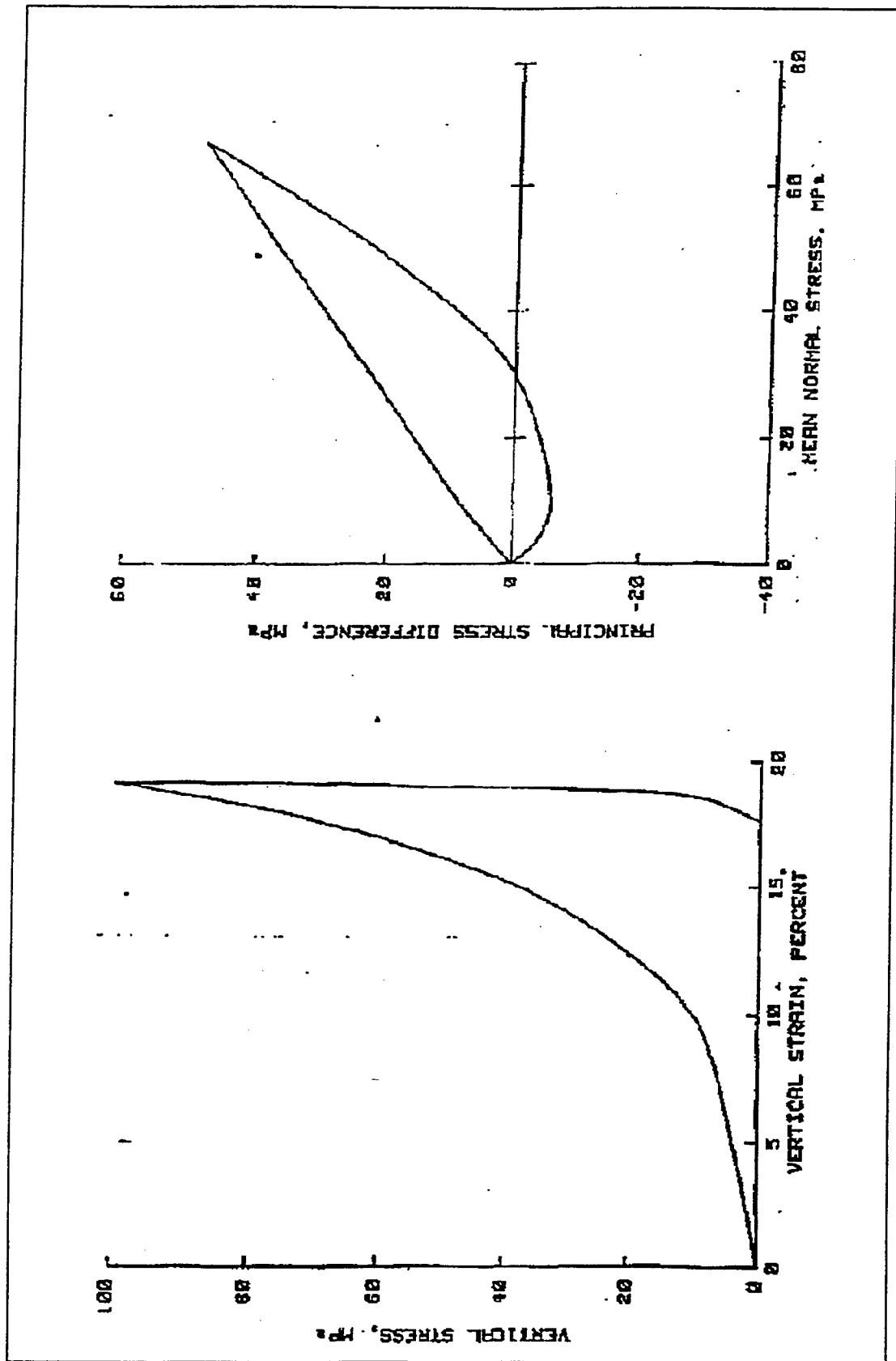


Figure 2.4. UX stress-strain relation and UX stress path for Yuma clayey sand with  $\gamma_d = 1.84 \text{ Mg/m}^3$  and  $w = 3.0$  percent





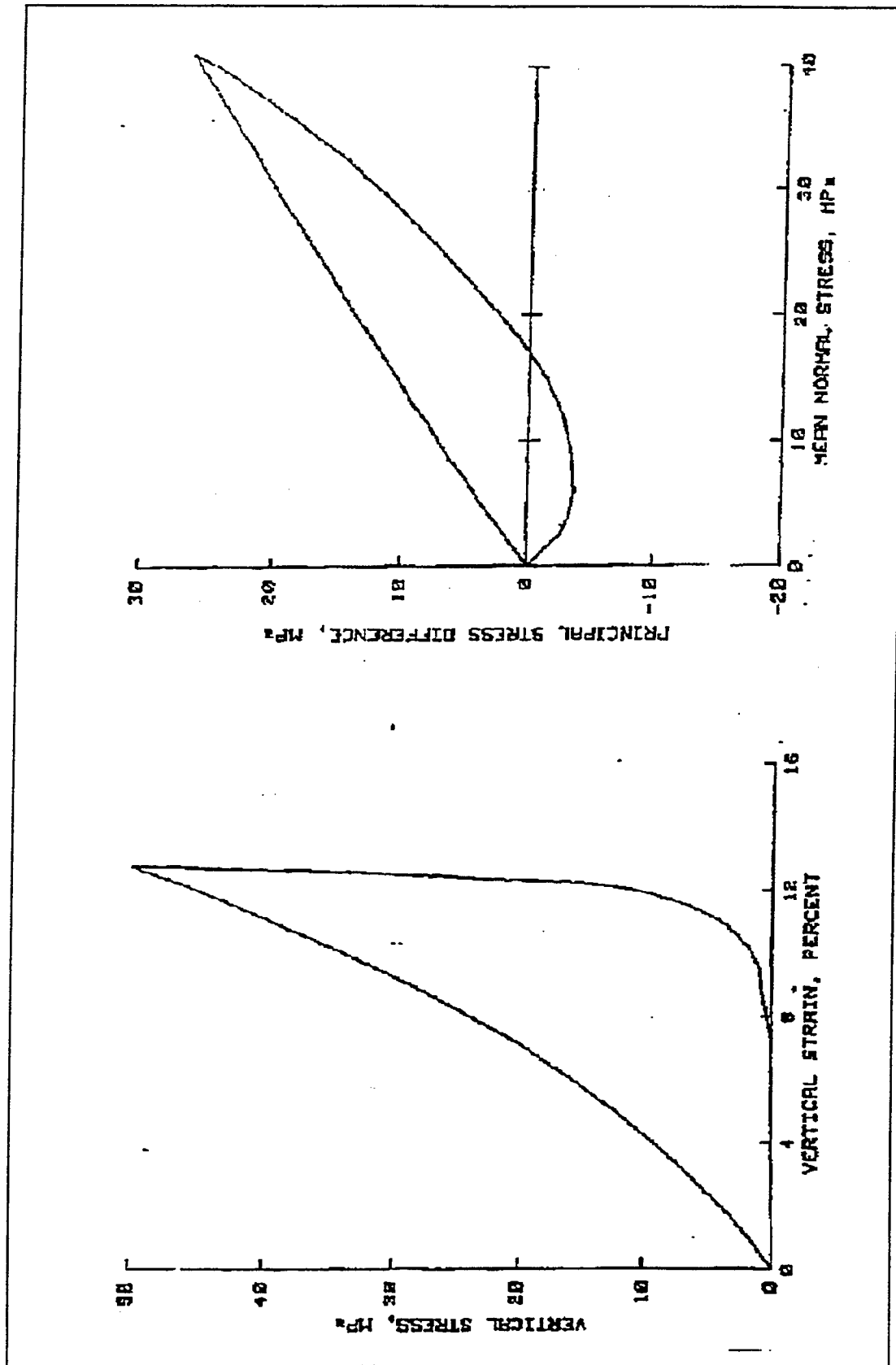


Figure 2.6. UX stress-strain relation and UX stress path for Vicksburg loess with  $\gamma_d = 1.62 \text{ Mg/m}^3$  and  $w = 11.9$  percent

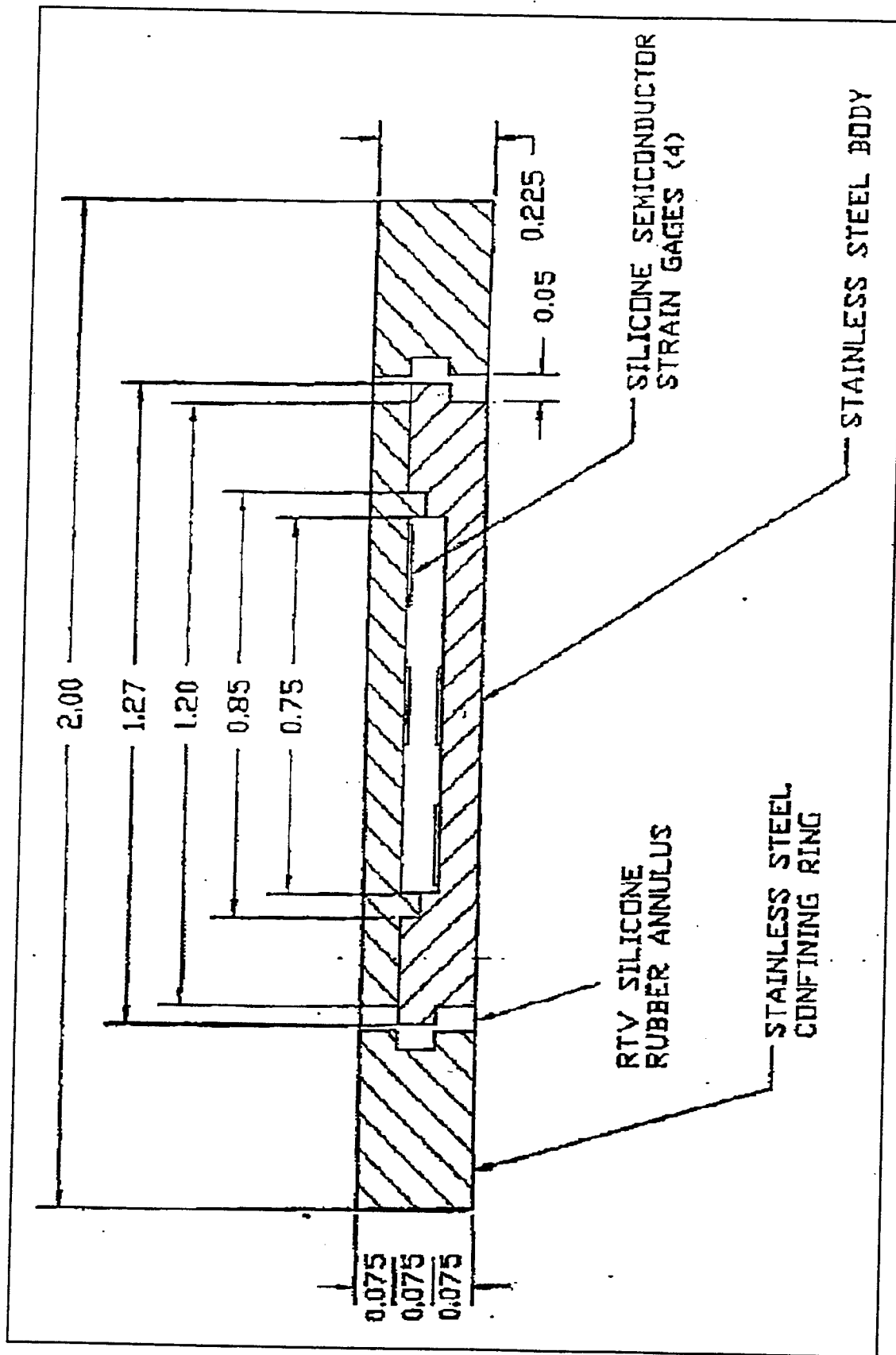


Figure 2.7. Cross-section of LRSE gage

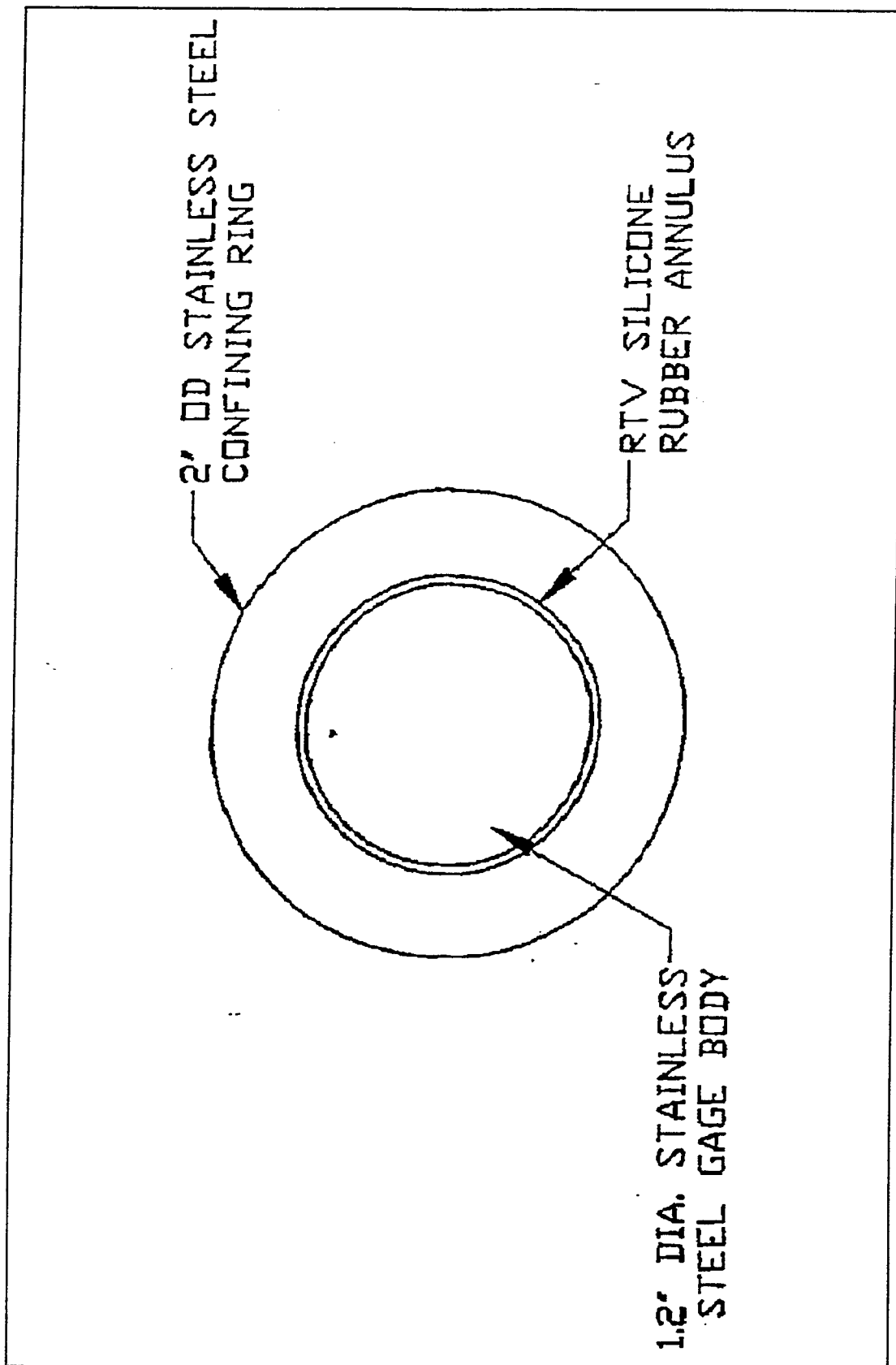


Figure 2.8. Plan view of LRSE gage with confining ring

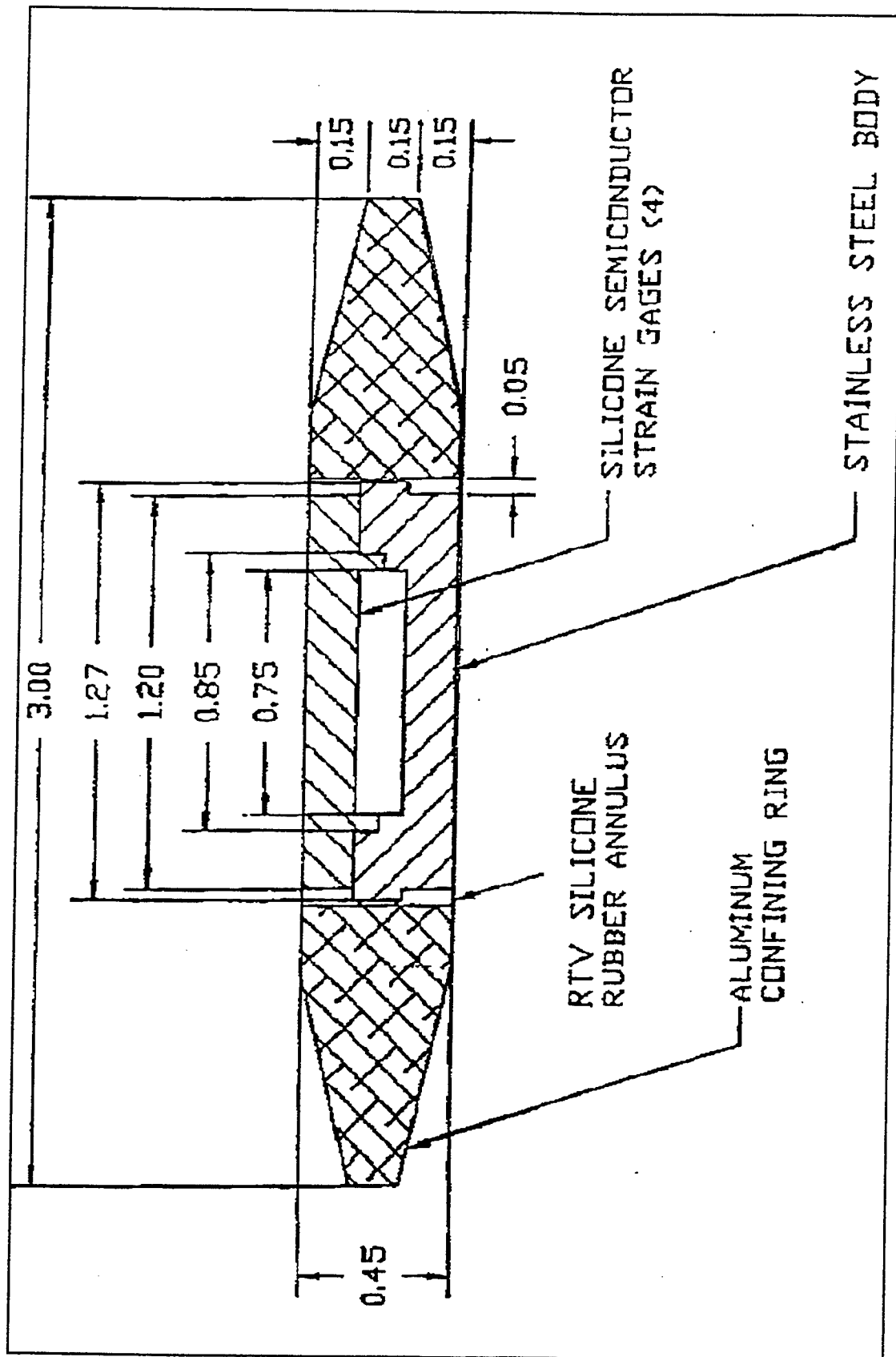


Figure 2.9. Cross-section of HRSE gage

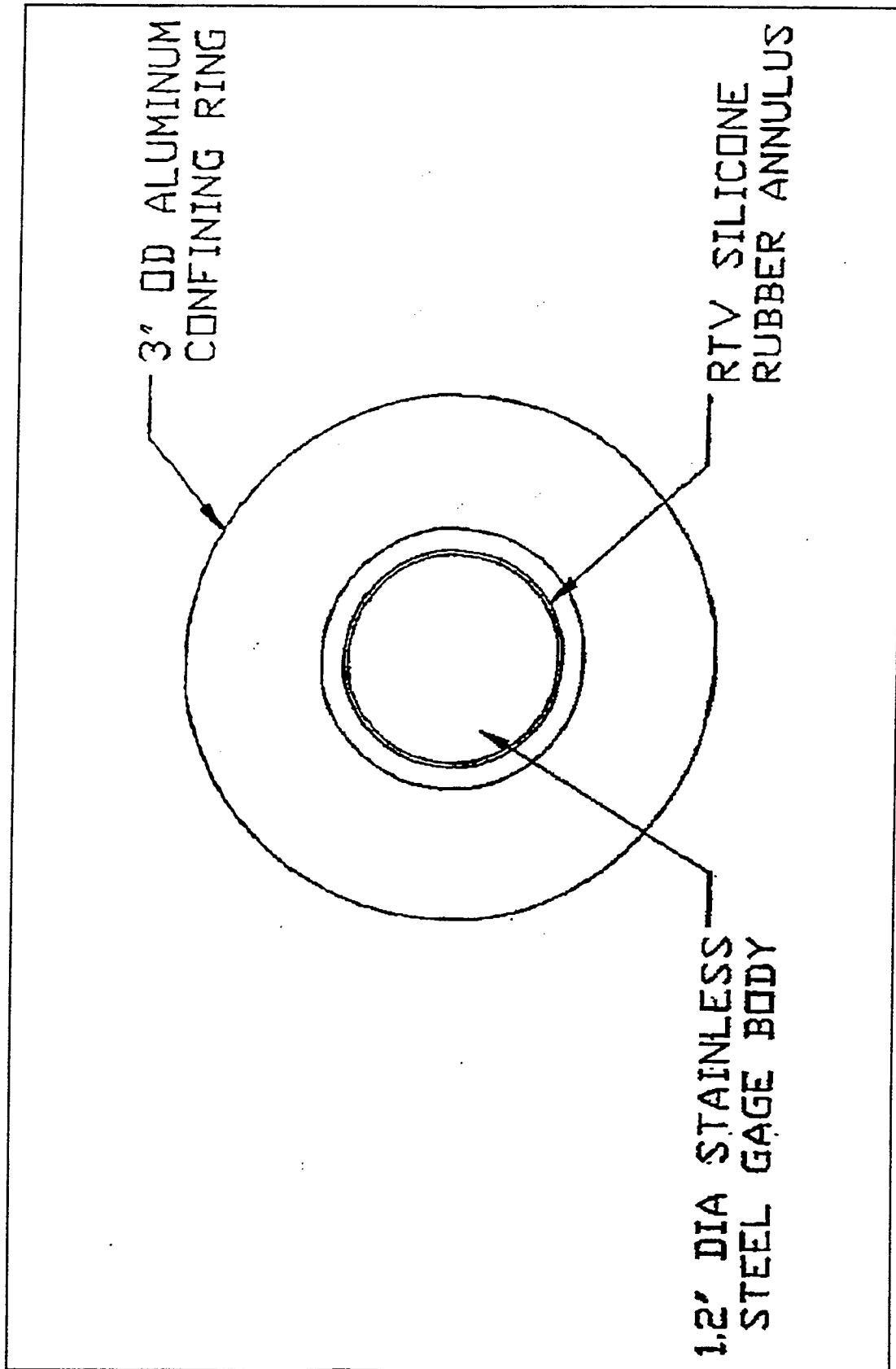


Figure 2.10. Plan view of HRSE gage with confining ring

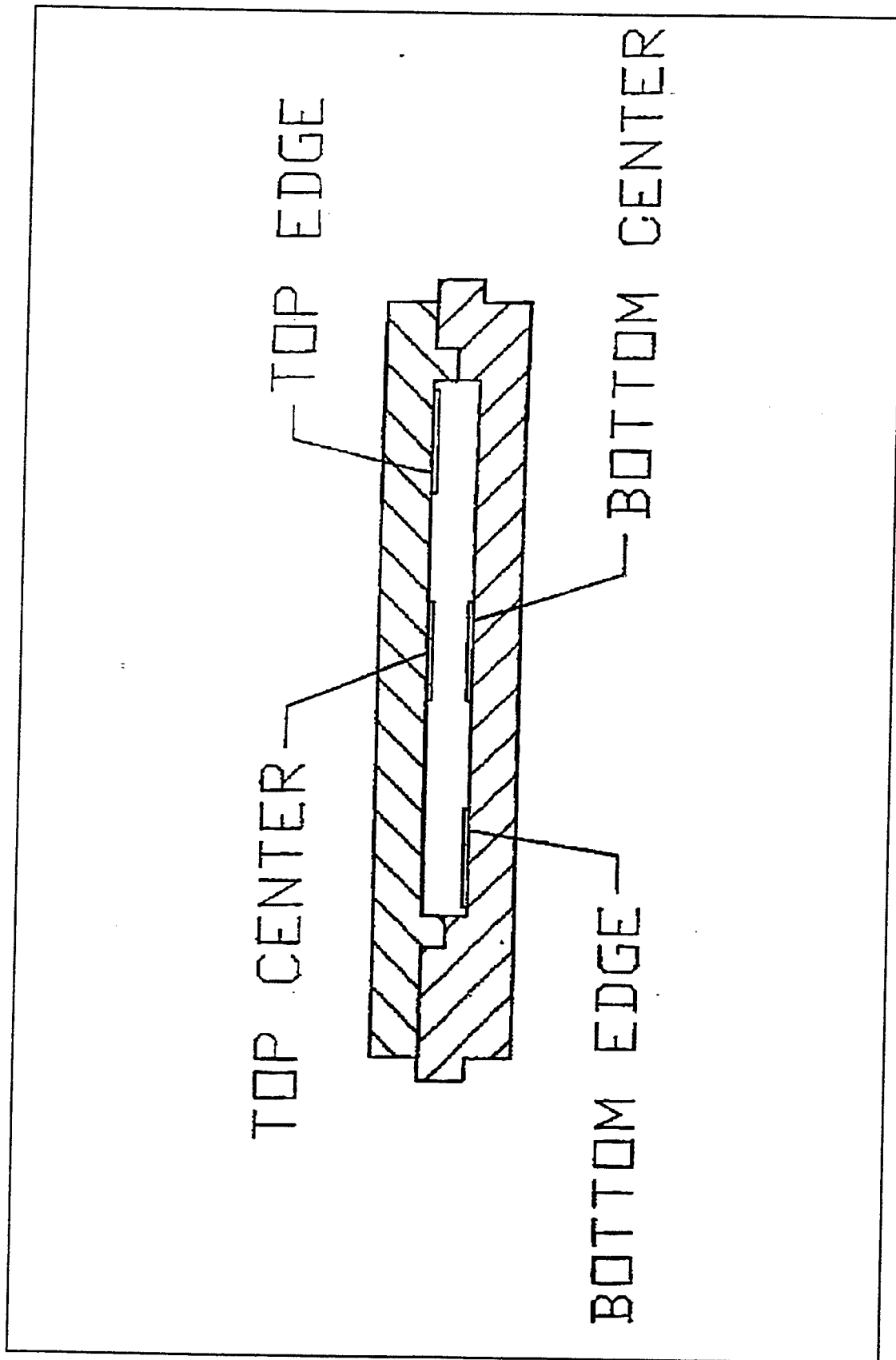


Figure 2.11. Nomenclature for individual strain gages in LRSE and HRSE soil stress gages

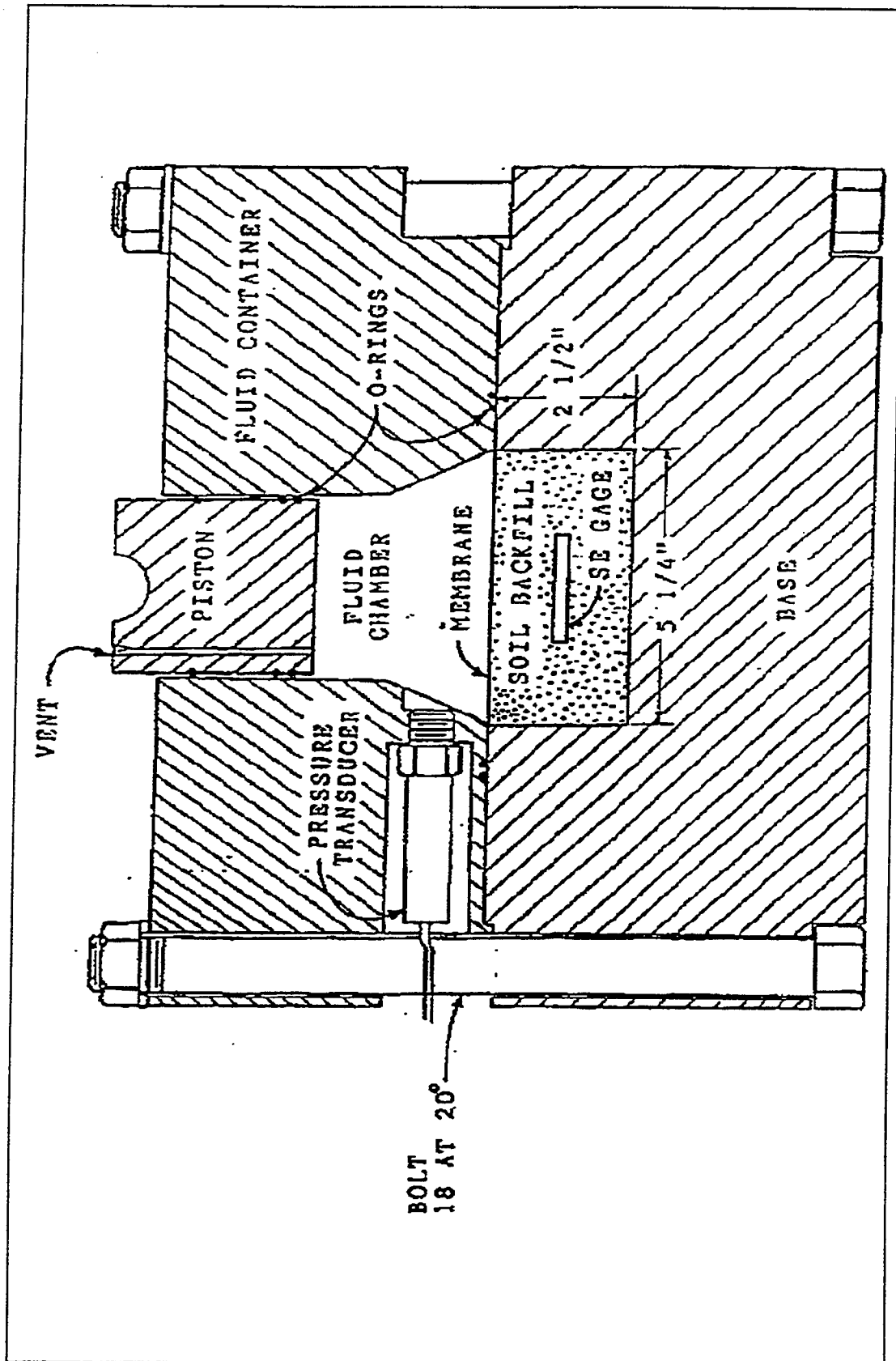


Figure 2.12. Test device used for soil-embedded gage calibrations



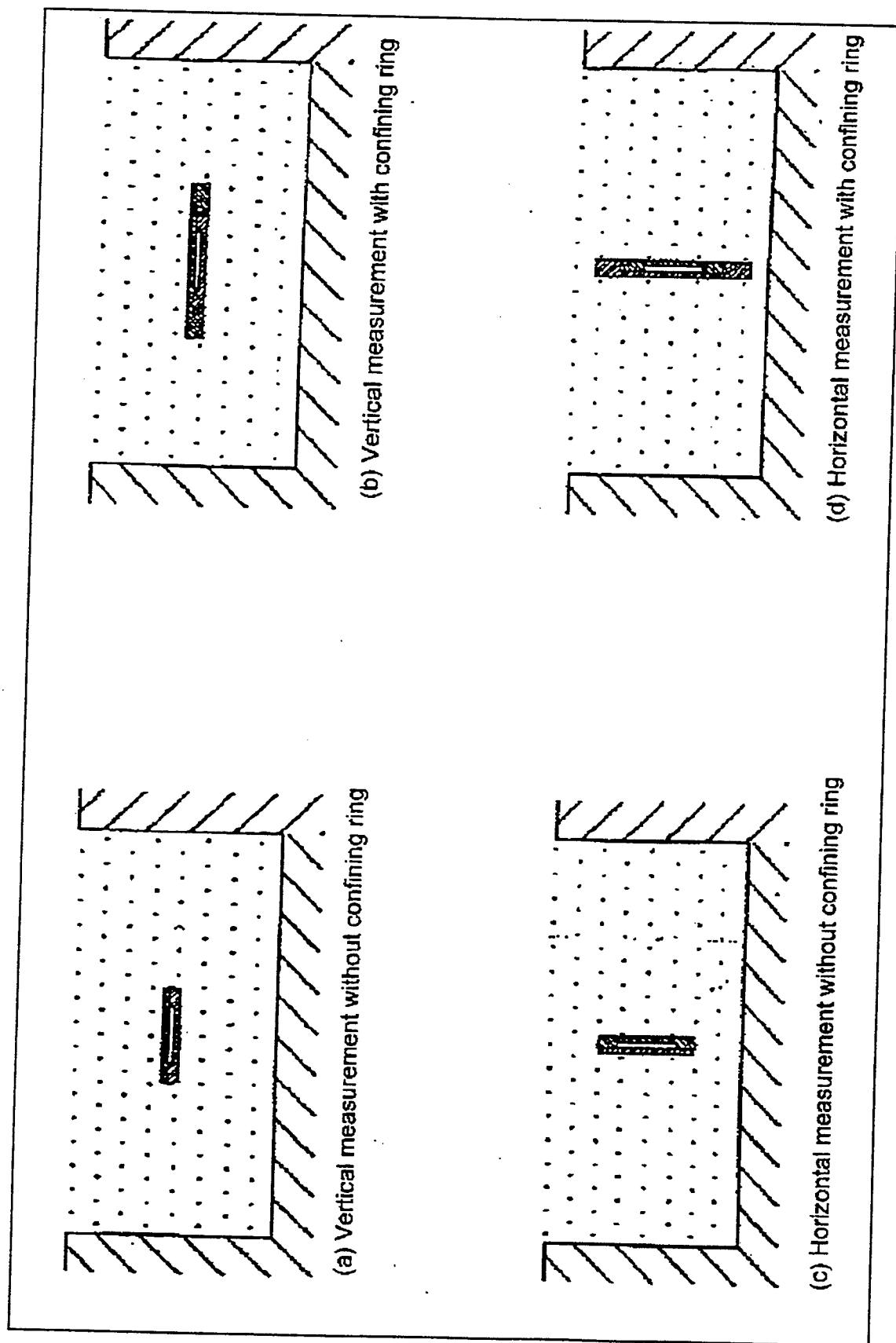


Figure 2.13. Four orientations for soil-embedded calibrations of LRSE gages

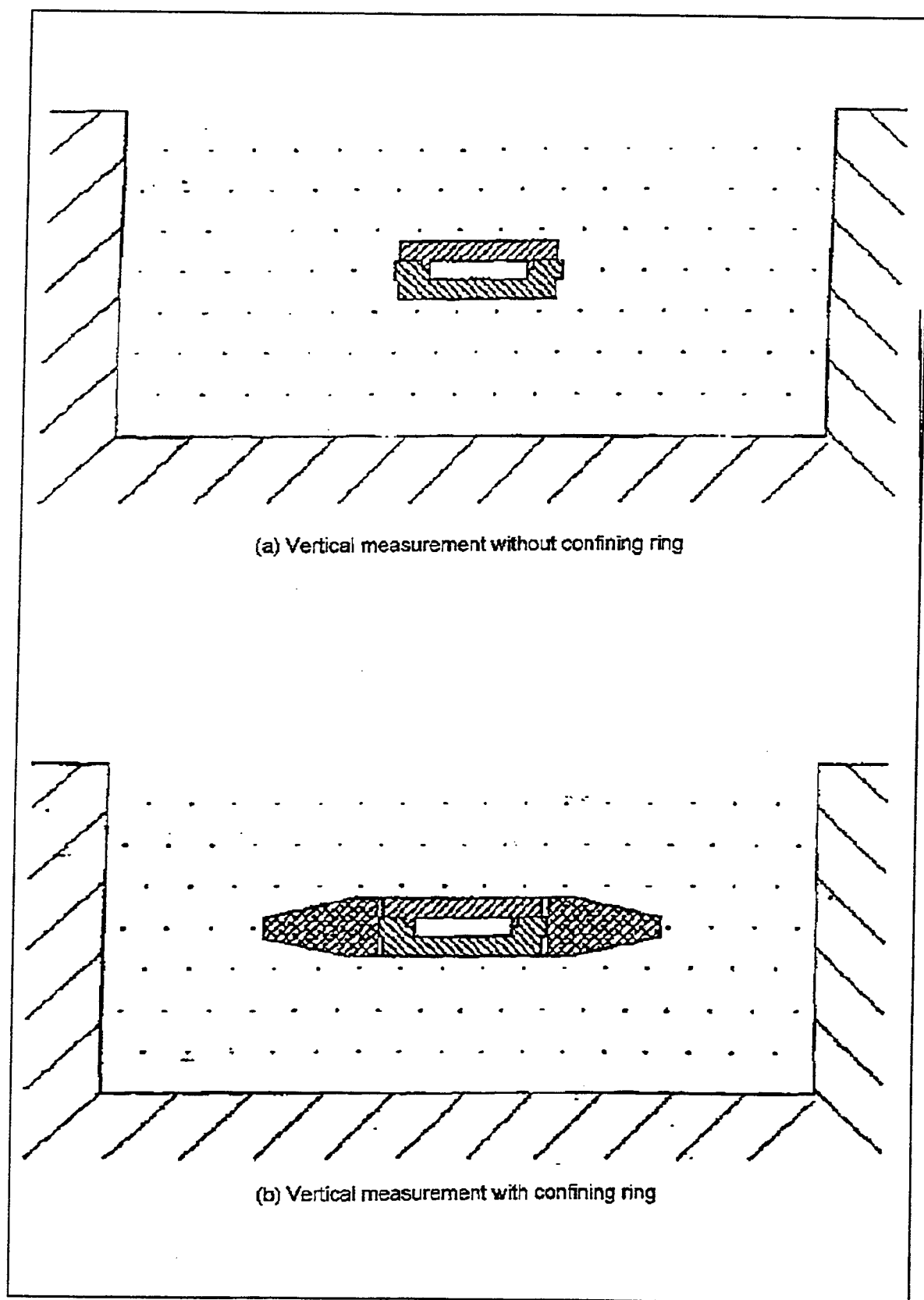


Figure 2.14. Two orientations for soil-embedded calibrations of HRSE gage

## 3 Test Results and Comparisons

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### Voltage Output Calibration Tests

To make a comparison between oil-immersed calibrations and soil-embedded calibrations, one must assume that the pressure applied to the top of the gage is equivalent to the pressure in the fluid chamber of the test device shown in Figure 2.12. The results of the loading portion of a hydrostatic calibration of a particular gage can be compared with a soil-embedded calibration of the same gage by comparing the associated  $C_a$  values for loading. These comparisons are shown in Table 3.1.

The  $C_a$  values for the soil-embedded calibrations of LRSE gages are consistently lower than the  $C_a$  values from hydrostatic calibrations; with only one exception, the  $C_a$  values for calibrations on gages embedded in Yuma clayey sand or Vicksburg loess (silty clay) are less than those for gages embedded in flume sand. Again, the  $C_a$  values for HRSE gages embedded in the three soils are less than the  $C_a$  value from hydrostatic calibrations; with only two exceptions, the  $C_a$  value for either Yuma clayey sand or Vicksburg loess is less than the  $C_a$  value from the flume sand calibration of the same gage.

Figure 3.1 compares typical loading and unloading results for LRSE gage calibrations; typical results for HRSE gages are compared in Figure 3.2. Linear elastic behavior is clearly evident in the hydrostatic calibrations of both the LRSE and HRSE gages. The loading portions of the soil-embedded calibrations on both LRSE and HRSE gages are slightly nonlinear; the unloading portions, however, are highly nonlinear. This produces significant hysteresis in the load-unload cycles, especially for the LRSE gage calibrations; HRSE gages display the same hysteretic behavior as LRSE gages during unloading but not to the same magnitude.

As shown in Figure 3.3, linear behavior for reloading of soil-embedded LRSE gage calibrations was typical; it was also typical for HRSE gage calibrations. The reloading cycle was linear in behavior from the initiation point on the unloading

cycle to the previous point of maximum applied stress. This linear reloading is characteristic of calibration tests run in each of the three soils.

## Strain Output Calibration Tests

### Oil-immersed calibrations

A typical loading cycle for the individual strain gages in a LRSE gage under hydrostatic loading is shown in Figure 3.4. The individual strain gages of the LRSE gages were linear in behavior for loading and unloading. Typically the edge strain gages were placed in compression to a magnitude that was half of that of the center gages, which were in tension. Figure 3.5 shows the total strain loading and unloading cycle from a hydrostatic calibration of a LRSE gage. Linear behavior is evident in both the loading and unloading portions of the total strain measurement.

The hydrostatic calibrations of the HRSE gages were not as repeatable as those for the LRSE gages. Load-unload output from the four individual strain gages in the bridge of a HRSE gage are shown in Figure 3.6; unlike the LRSE gages, all four strain gages record tensile strains. The magnitudes of bottom and top gages were not equivalent as they were in the hydrostatic calibrations of the LRSE gages. The combined or total strain results of loading and unloading are presented in Figure 3.7. The loading portion is essentially linear; the unloading portion is slightly nonlinear, producing some hysteresis in the load-unload cycle.

### Soil-embedded calibrations

Strain output tests were conducted on both LRSE and HRSE gages embedded in flume sand. Both gage types were tested with and without a confining ring. LRSE gages were oriented for both vertical and horizontal measurements, while the HRSE gage was tested only when oriented for vertical measurements. The orientations for the LRSE and HRSE gages are shown in Figures 2.13 and 2.14, respectively. Typical results for each orientation are presented herein along with results of tests conducted with and without a confining ring.

As with the voltage output calibration tests, slight nonlinear behavior is evident in the loading portions of the LRSE strain gage records for soil-embedded calibrations. The individual strain gage output from an LRSE gage during the loading cycle, with and without a confining ring, and oriented for vertical stress measurement, are shown on Figures 3.8 and 3.9. A with/without confining ring comparison of the total strain output from a LRSE gage oriented for vertical stress measurement is presented in Figure 3.10. The load-unload cycles in these flume sand calibration tests are very hysteretic in nature. There is little effect, however, on the loading or unloading response of the LRSE gage due to the confining ring.

The individual strain output from a LRSE gage placed for horizontal stress measurements is displayed in Figure 3.11 for a calibration test with a confining ring, and in Figure 3.12 for a test without a confining ring. It should be noted

that the vertical stress plotted in those figures is not the pressure applied to the sensing face of the gage, but is the pressure applied to the surface of the soil sample. The horizontal stress or pressure applied to the sensing face of the gage is a function of the vertical stress applied to the surface of the sample and the UX stress path shown in Figure 2.2. Total strain measurements from a LRSE gage oriented for horizontal measurement with and without a confining ring are compared in Figure 3.13. When the LRSE gages are oriented for horizontal stress measurement, there is a large difference in total strain output for gages calibrated in soil with and without the confining ring. The total strain for the gage with the confining ring is consistently higher during both loading and unloading than for the gage without the confining ring. Again, only slight nonlinear behavior is evident during loading; but, significant hysteresis is apparent in the unload cycle due to the highly nonlinear behavior during unloading.

HRSE soil-embedded gage calibrations have more scatter than the LRSE gage data. Individual strain gage loading results are plotted versus vertical stress or pressure for a HRSE gage with the confining ring in Figure 3.14, and without the confining ring in Figure 3.15. The difference in the output from the center gages is negligible, but the difference in the response of the edge gages is significant. The edge gages in the tests with a confining ring recorded a tensile strain, whereas the edge gages in the test without a confining ring recorded compressive strains. The total response is shown in Figure 3.16. The total strain output with and without the confining ring is effectively the same up to about 2000 psi of pressure. Above 2000 psi, the total strain output is less in the gage with the confining ring. Hysteresis is evident in the load-unload cycle for the HRSE gage, but not to the degree displayed in the load-unload behavior of the LRSE gages.

**Table 3.1**  
**Comparison of Oil-Immersed and Soil-Embedded Calibration Constants for Loading**

Gage Type	Serial Number	Calibration Constants (Ca) for Loading			
		Hydraulic Oil	Flume Sand	Clayey Sand	Silty Clay
LRSE	6-3955-84	2980.2	3016.1 (Avg of 6)	2925.3 (Avg of 6)	2651.5 (Avg of 3)
	2-3692-84	3170.3	2949.7	2715.9	2810.5
	2-3694-84	3161.8	2880.0	3173.5	2838.9
	2-3703-84	3497.3	3466.0	3446.4	3150.1
	2-3710-84	3431.0 (Avg of 7)	3211.5	3113.7	2879.4
	9-3603-83	3528.0	3099.3	3057.2	2881.9
	9-3611-83	3670.1	3551.1	3106.2	3170.3
HRSE	9-3968-84	15629.5	14837.1	13890.9	
	8-3940-84	15079.4 (Avg of 7)		12368.6 (Avg of 6)	
	8-3941-84	14287.2	13209.6	13923.2	
	8-3951-84	16100.2	15636.8	12771.0	
	10-3633-83	13298.0			
	10-3627-83	11981.0			
	10-3630-83	13540.6			
	6-3515-83	12790.5			
	6-3518-83	12143.1			
	10-3620-83	12242.8			
	10-3623-83	11633.5			
	10-3625-83	12566.7			
	10-4000-84	14064.0 (Avg of 7)	11157.5 12991.5 (Avg of 6)	11655.6	9969.7 11584.9 11348.3 12028.8 8927.3 9653.5 (Avg of 4) 9996.6

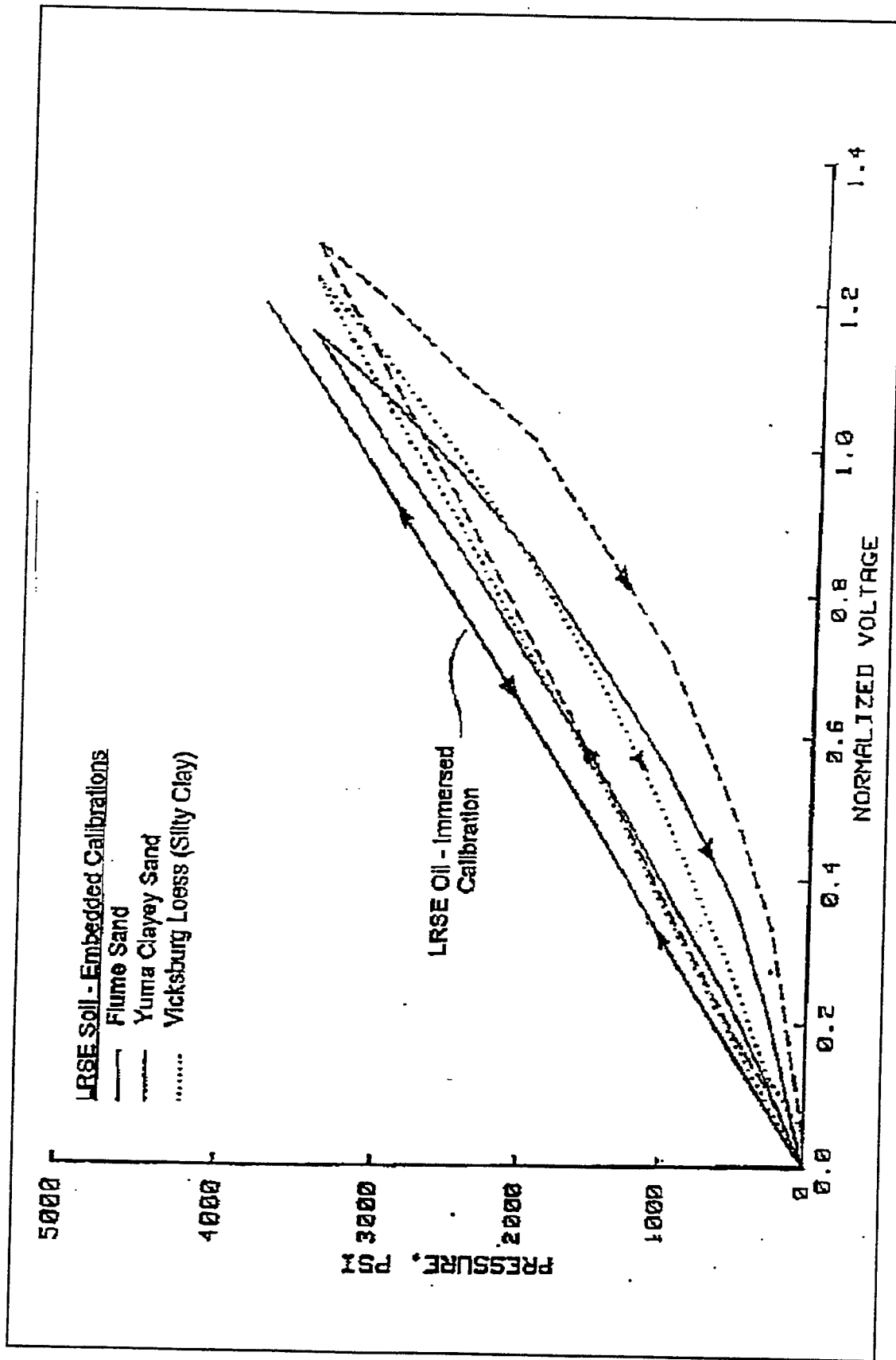


Figure 3.1. Typical loading and unloading results from calibrations of a LRSE gage

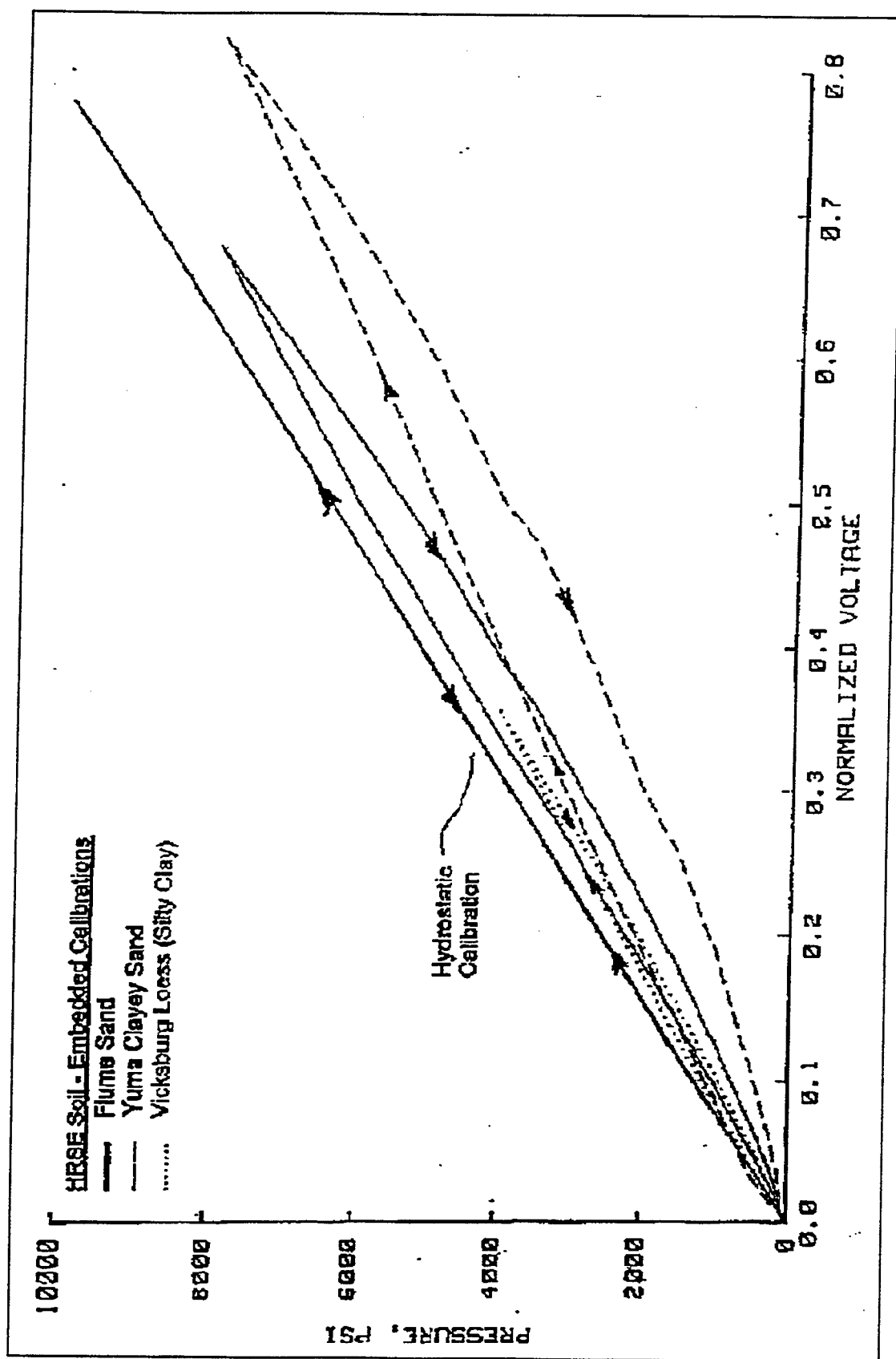


Figure 3.2. Typical loading and unloading results from calibrations of a HRSE gage



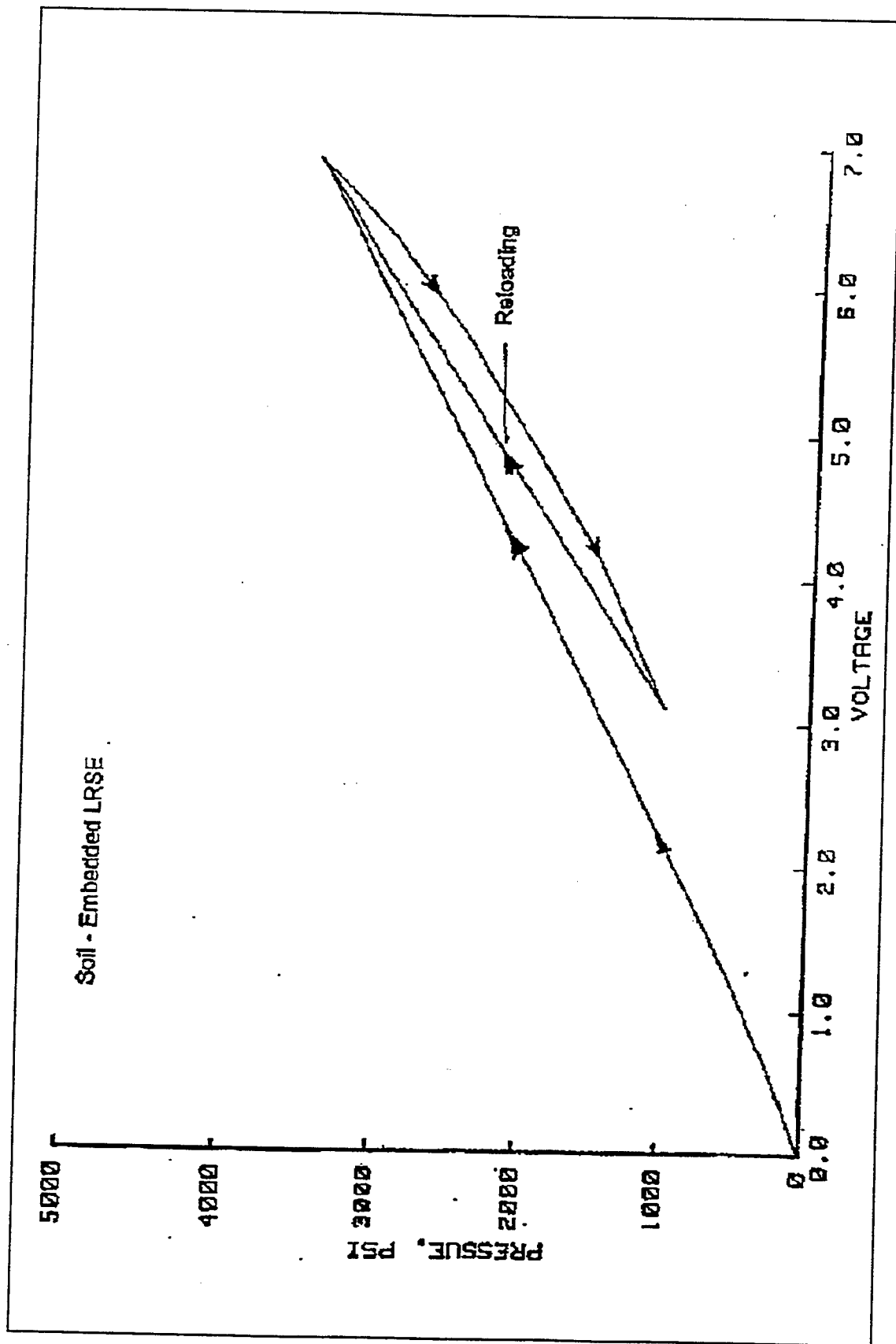


Figure 3.3. Typical soil-embedded calibration of a LRSE gage with a linear reloading cycle

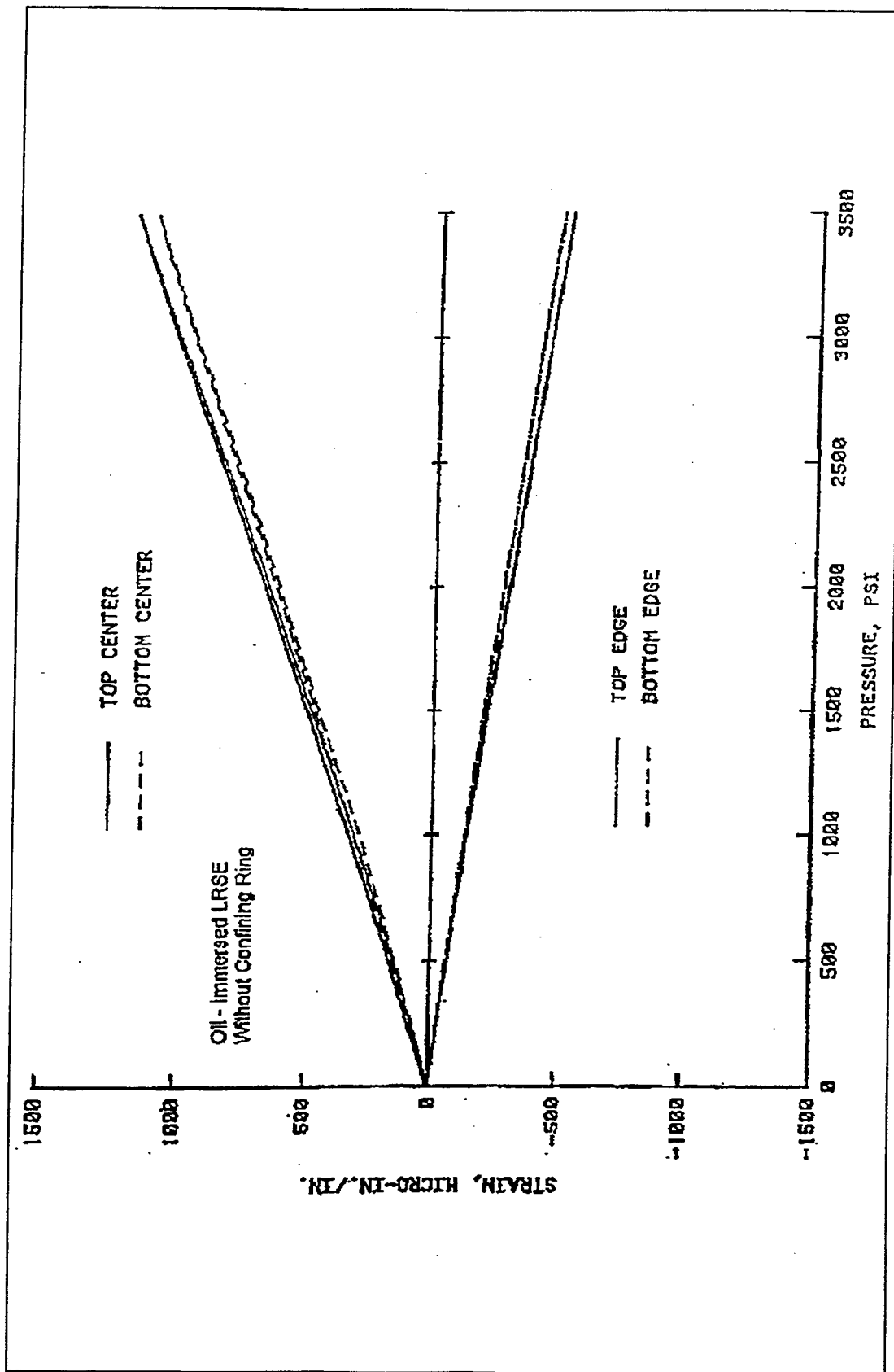


Figure 3.4. Individual strain gage measurements from hydrostatic calibration of a LRSE gage

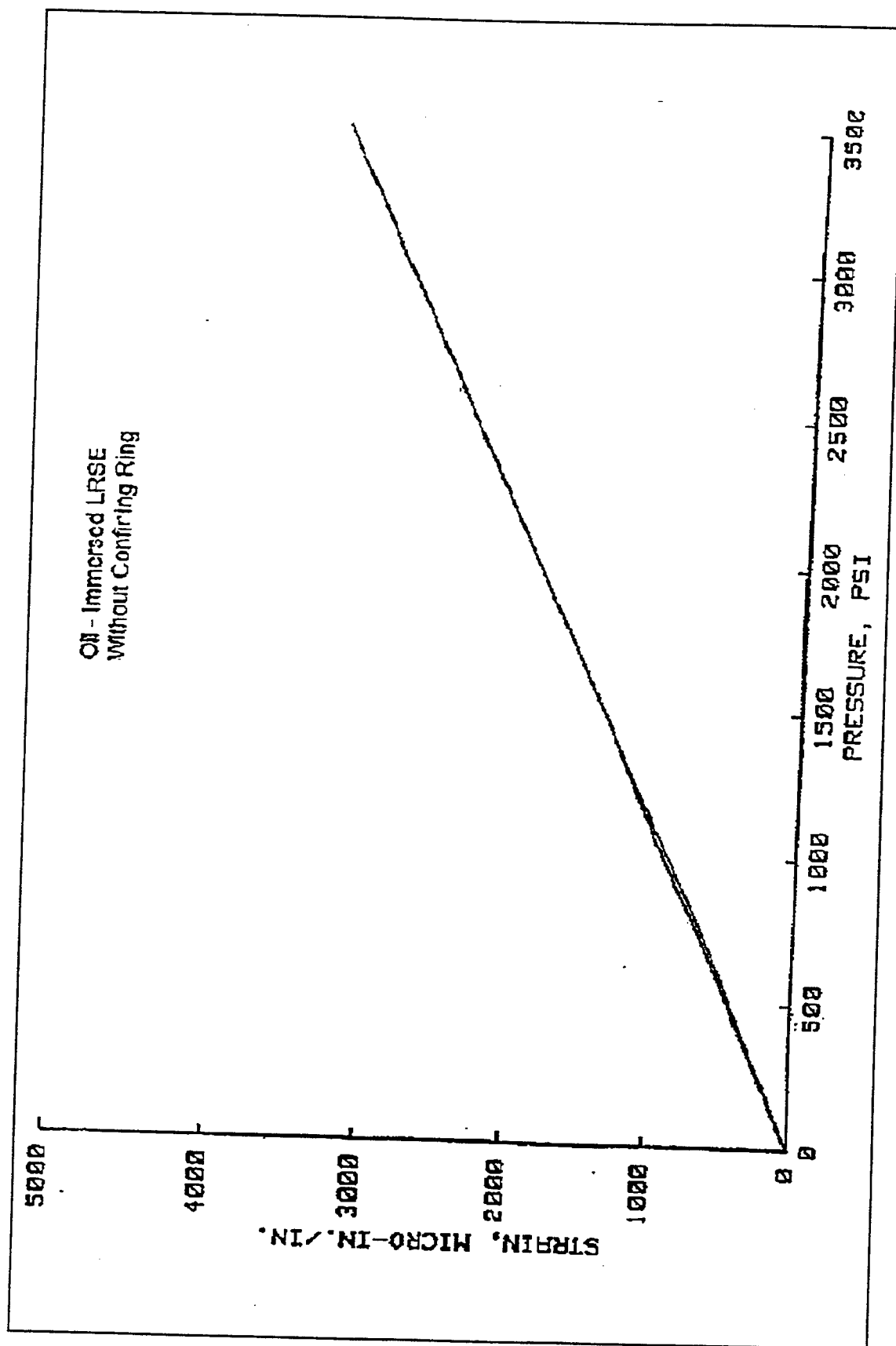


Figure 3.5. Total strain measurement from hydrostatic calibration of a LRSE gage

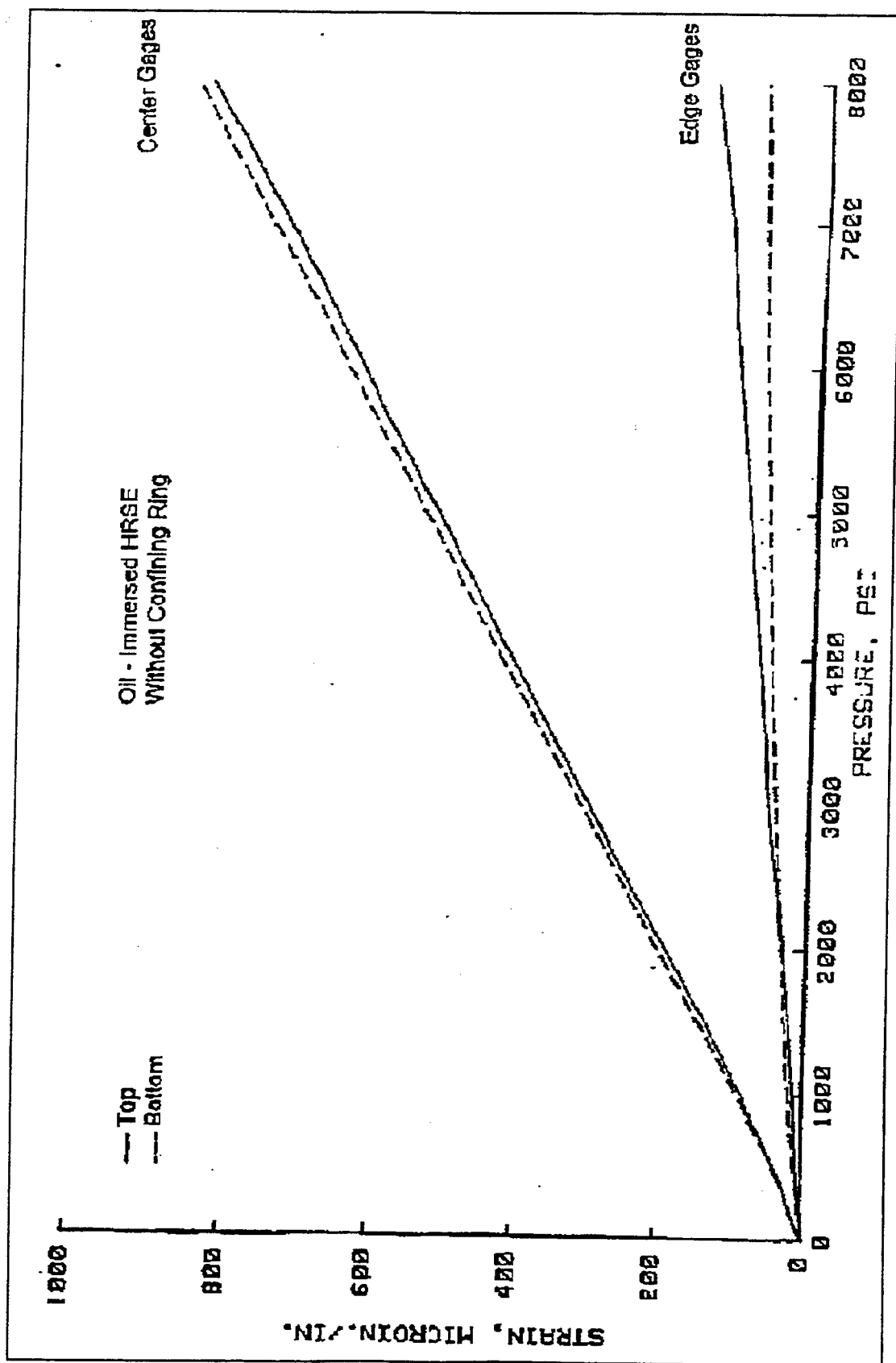


Figure 3.6. Individual strain gage measurements from hydrostatic calibration of a HRSE gage

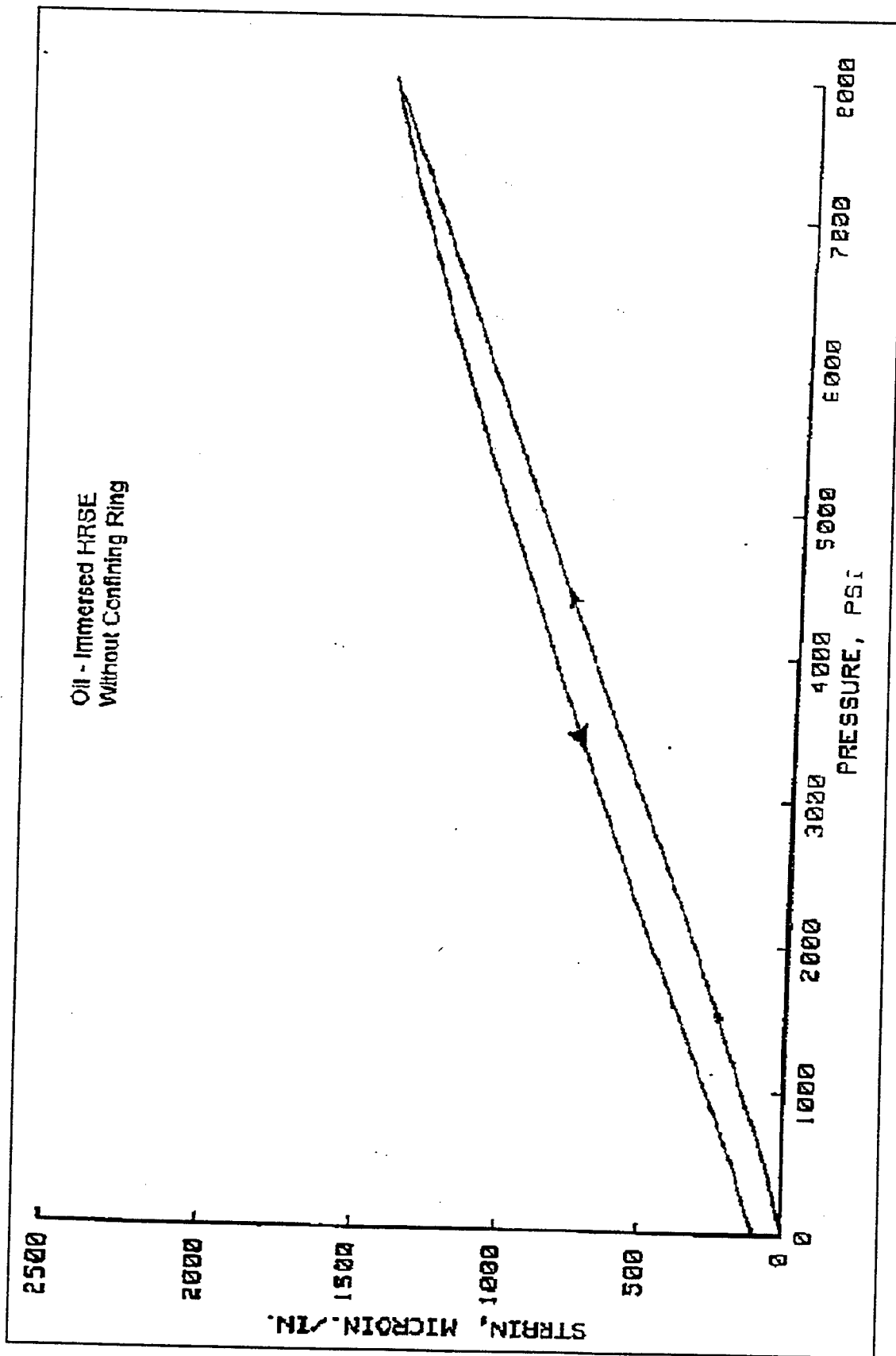


Figure 3.7. Total strain measurement from hydrostatic calibration of a HRSE gage

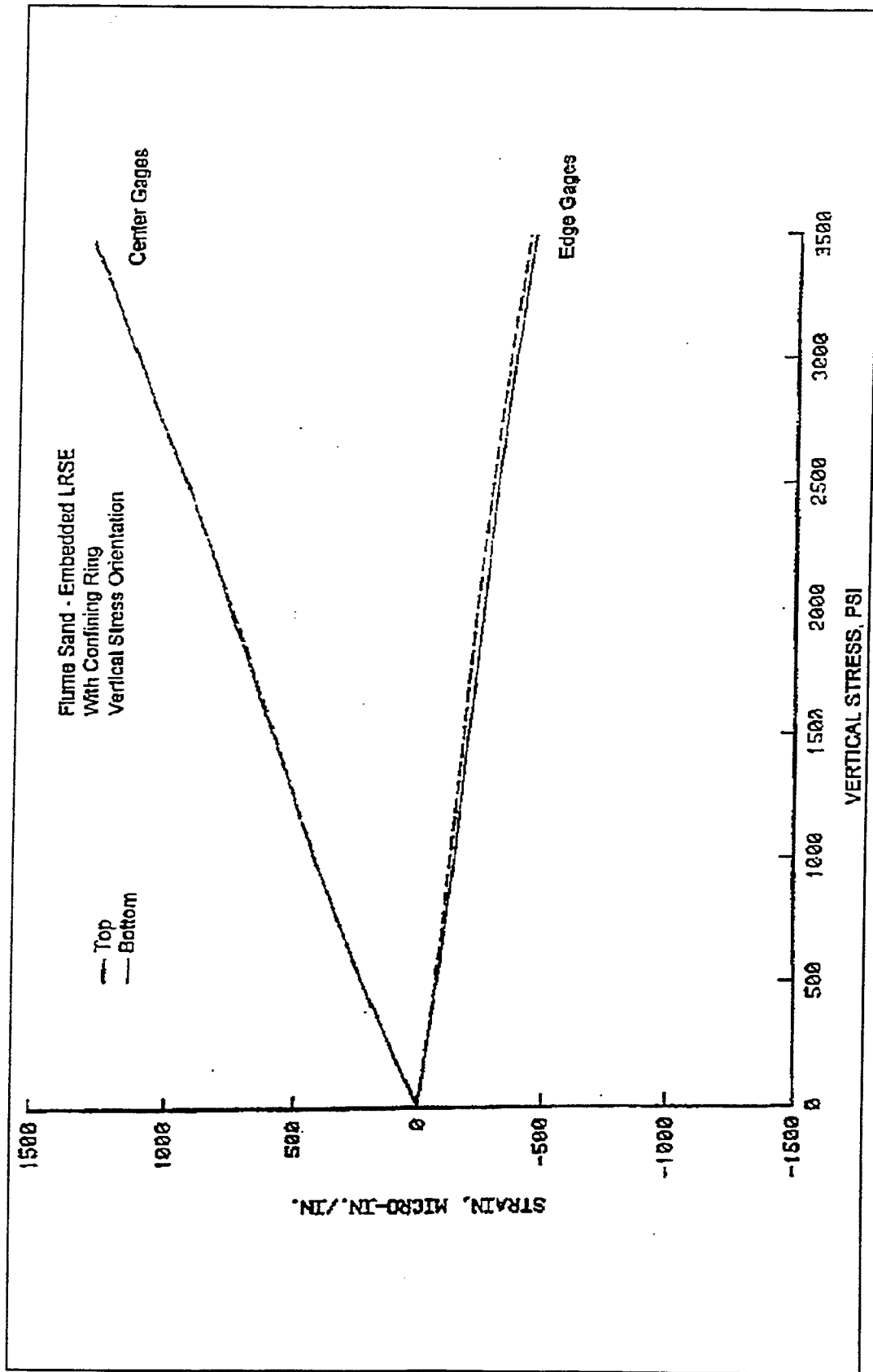


Figure 3.8. Individual strain gage measurements from flume sand-embedded calibration of a LRSE gage with a confining ring (oriented for vertical stress measurement)

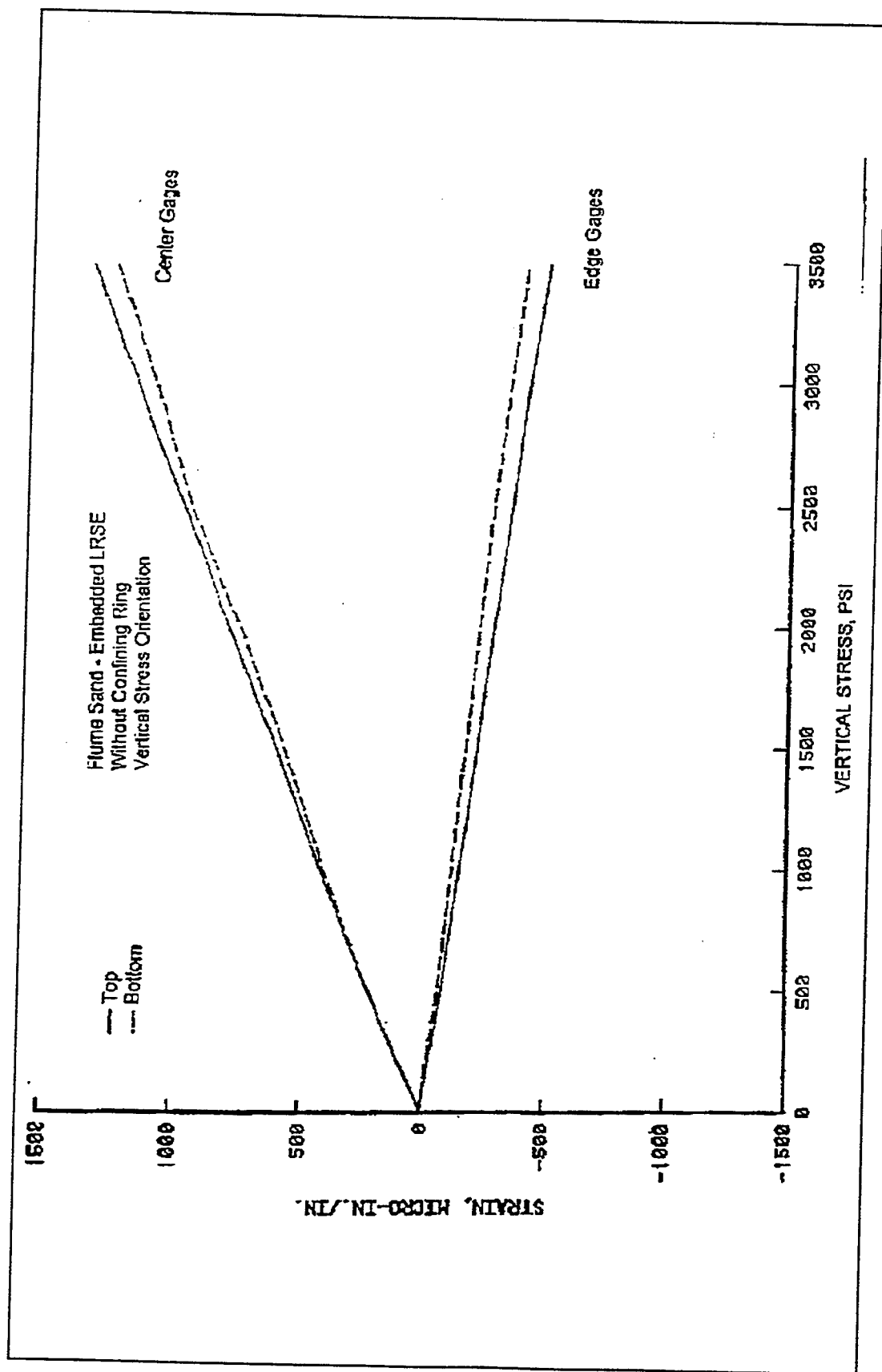


Figure 3.9. Individual strain gage measurements from flume sand-embedded calibration of a LRSE gage without a confining ring (oriented for vertical stress measurement)

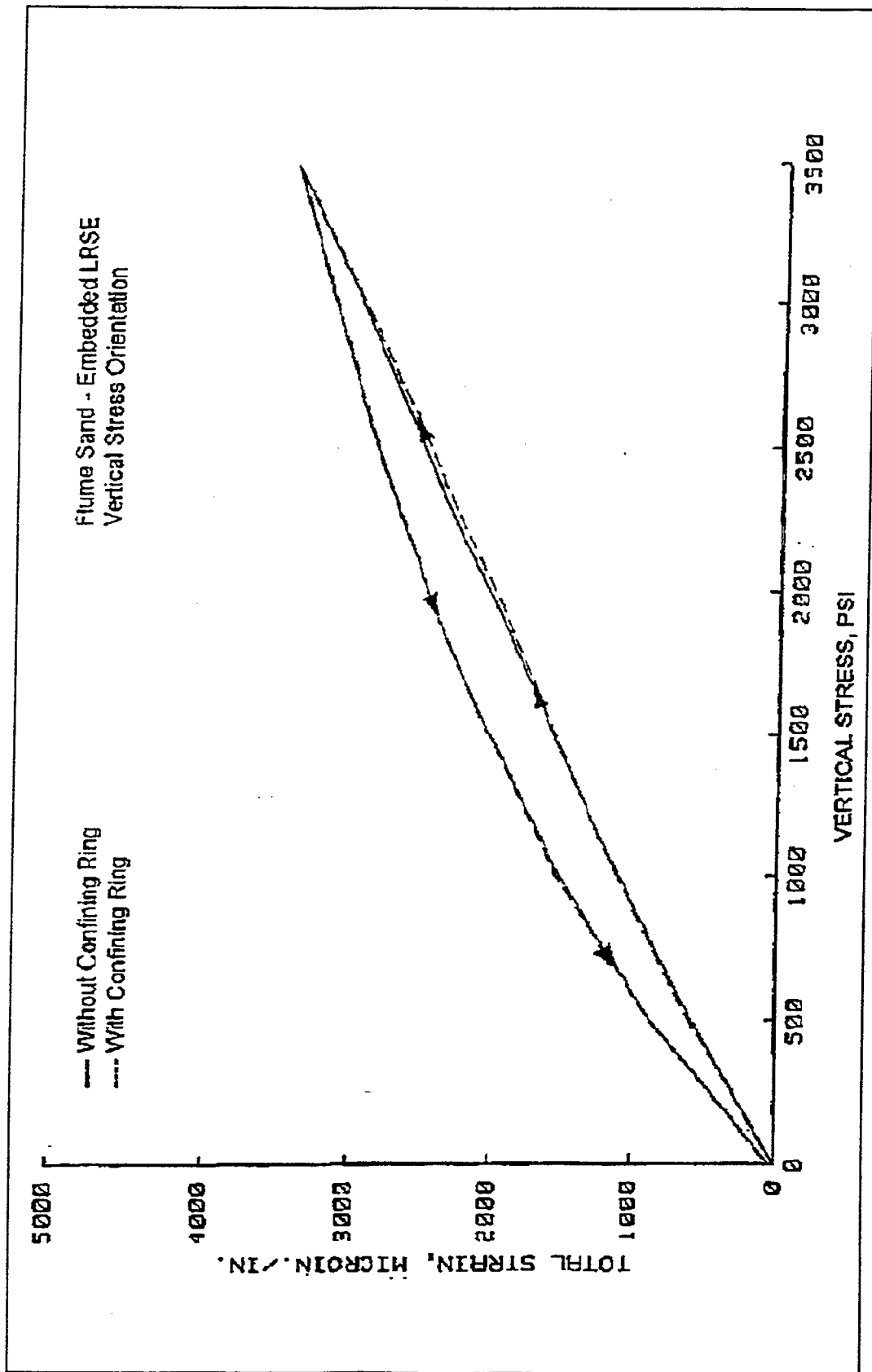


Figure 3.10. Comparison of total strain measurements from flume sand-embedded calibrations of a LRSE gage with and without a confining ring (oriented for vertical stress measurement)



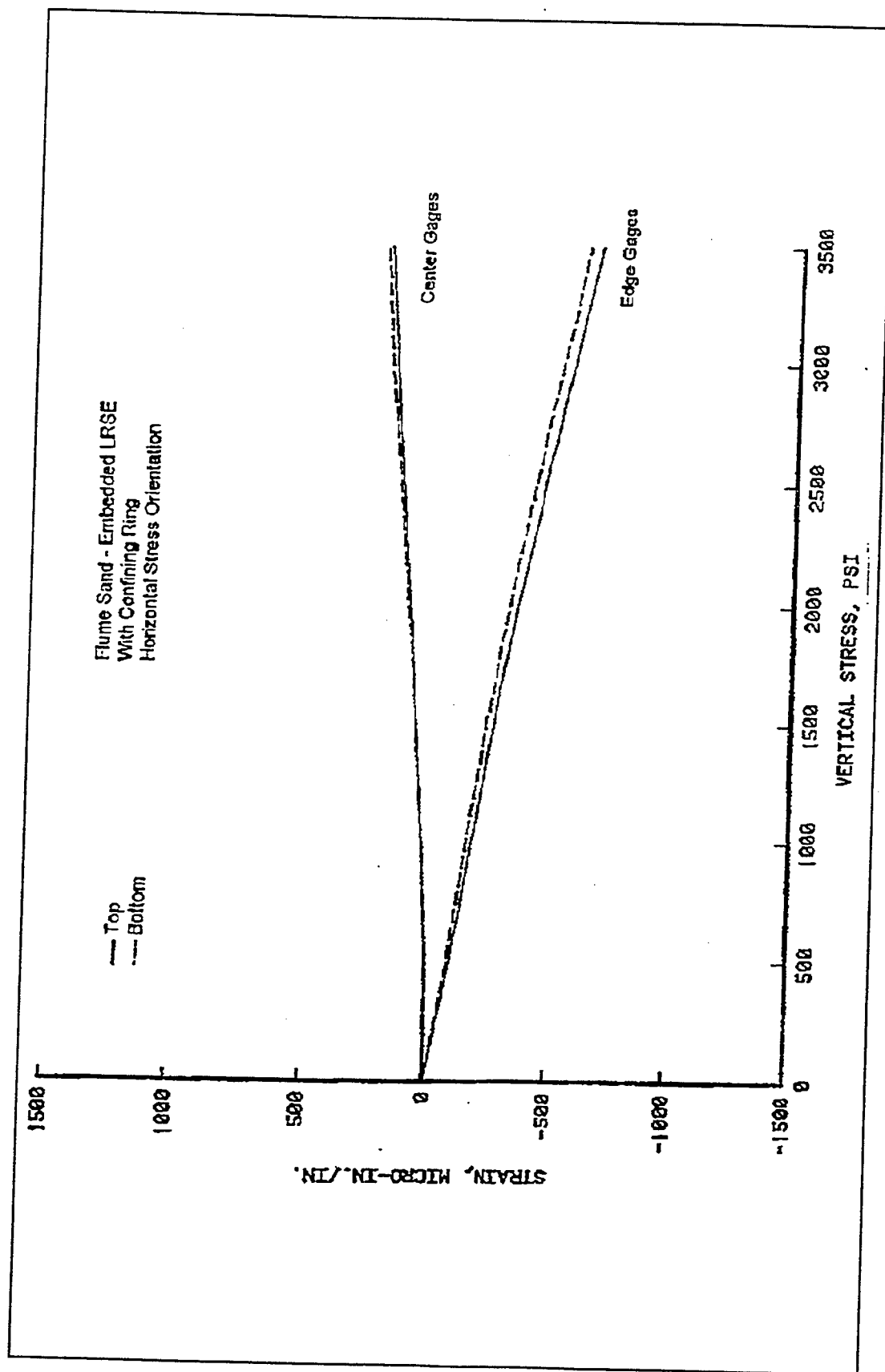


Figure 3.11. Individual strain measurements from flume sand-embedded calibration tests of a LRSE gage with a confining ring (oriented for horizontal stress measurement)

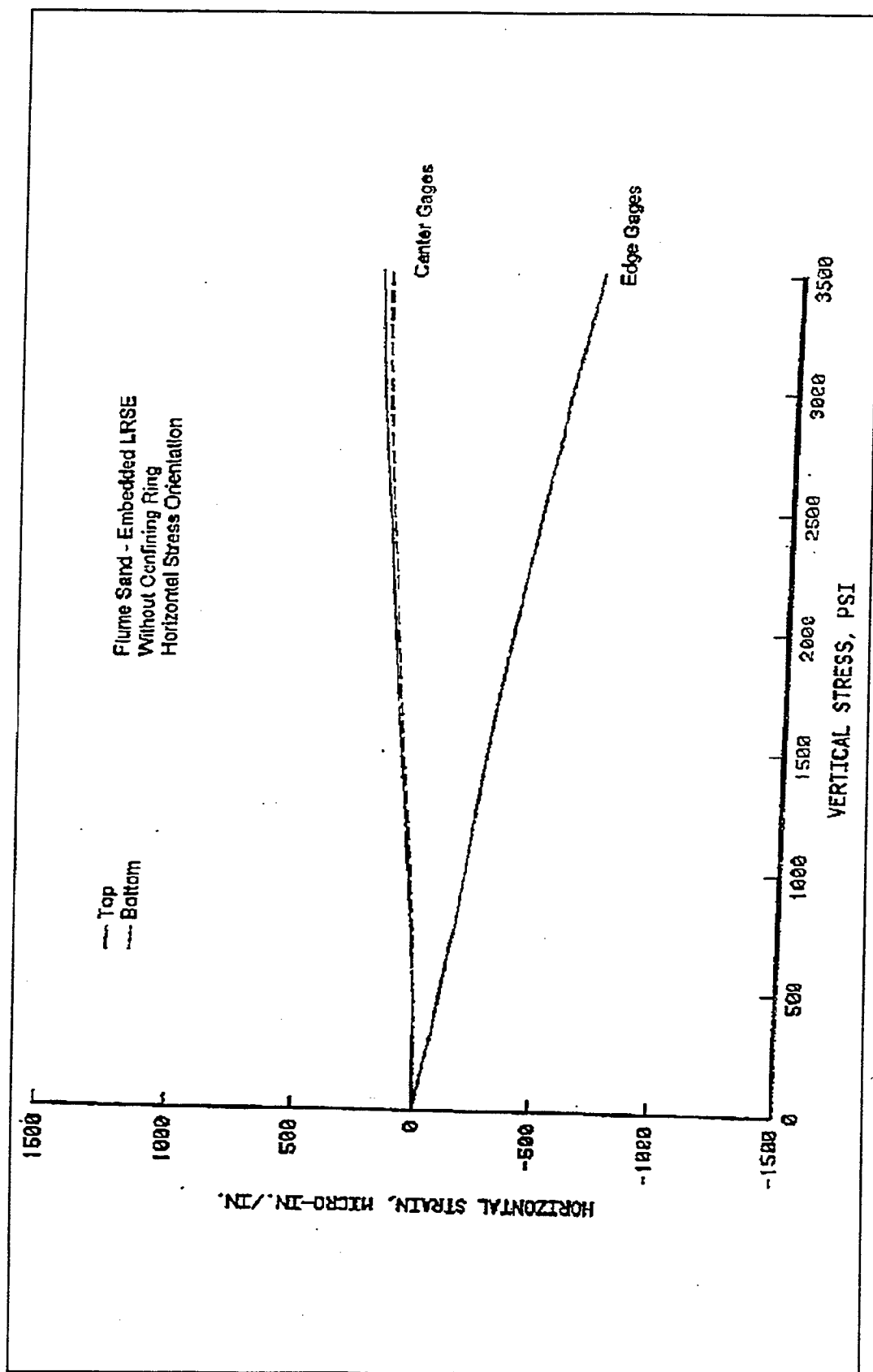


Figure 3.12. Individual strain gage measurements from flume sand-embedded calibration tests without a confining ring (oriented for horizontal stress measurement)

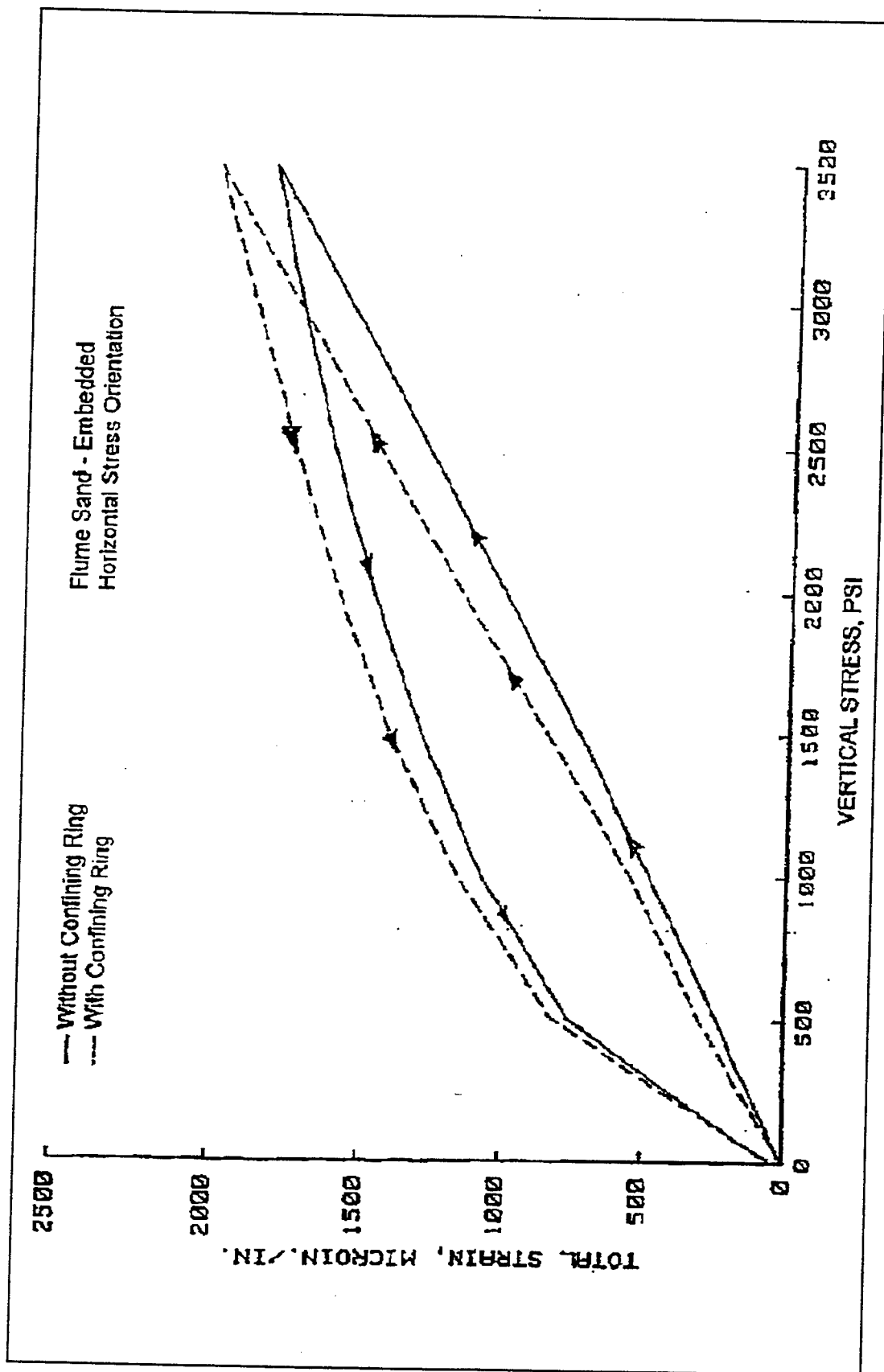


Figure 3.13. Comparison of total strain measurements from flume sand-embedded calibrations of a LRSE gage (oriented for horizontal stress measurement)

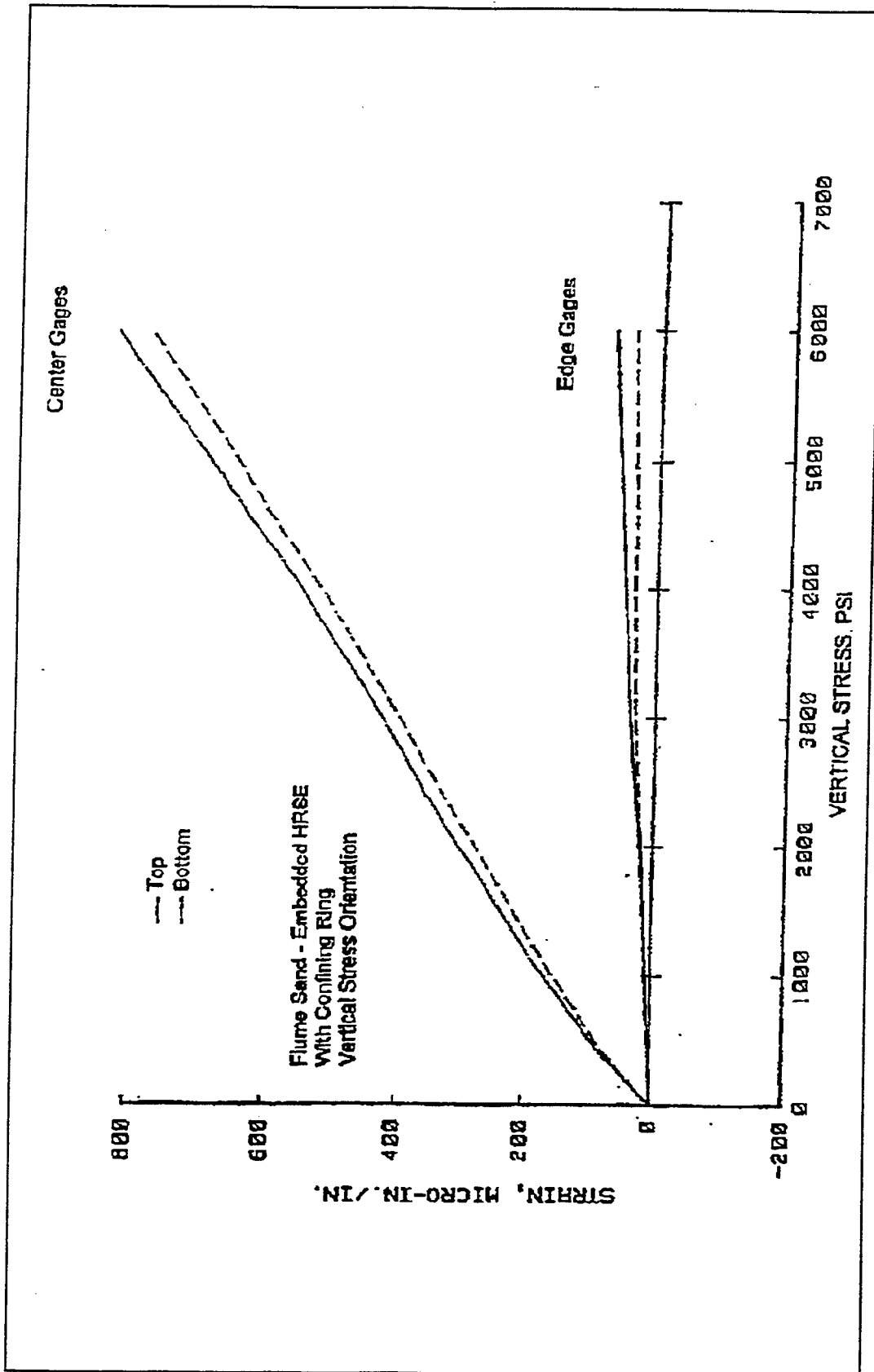


Figure 3.14. Individual strain gage measurements from flume sand-embedded calibration tests of a HRSE gage with a confining ring (oriented for vertical stress measurement)

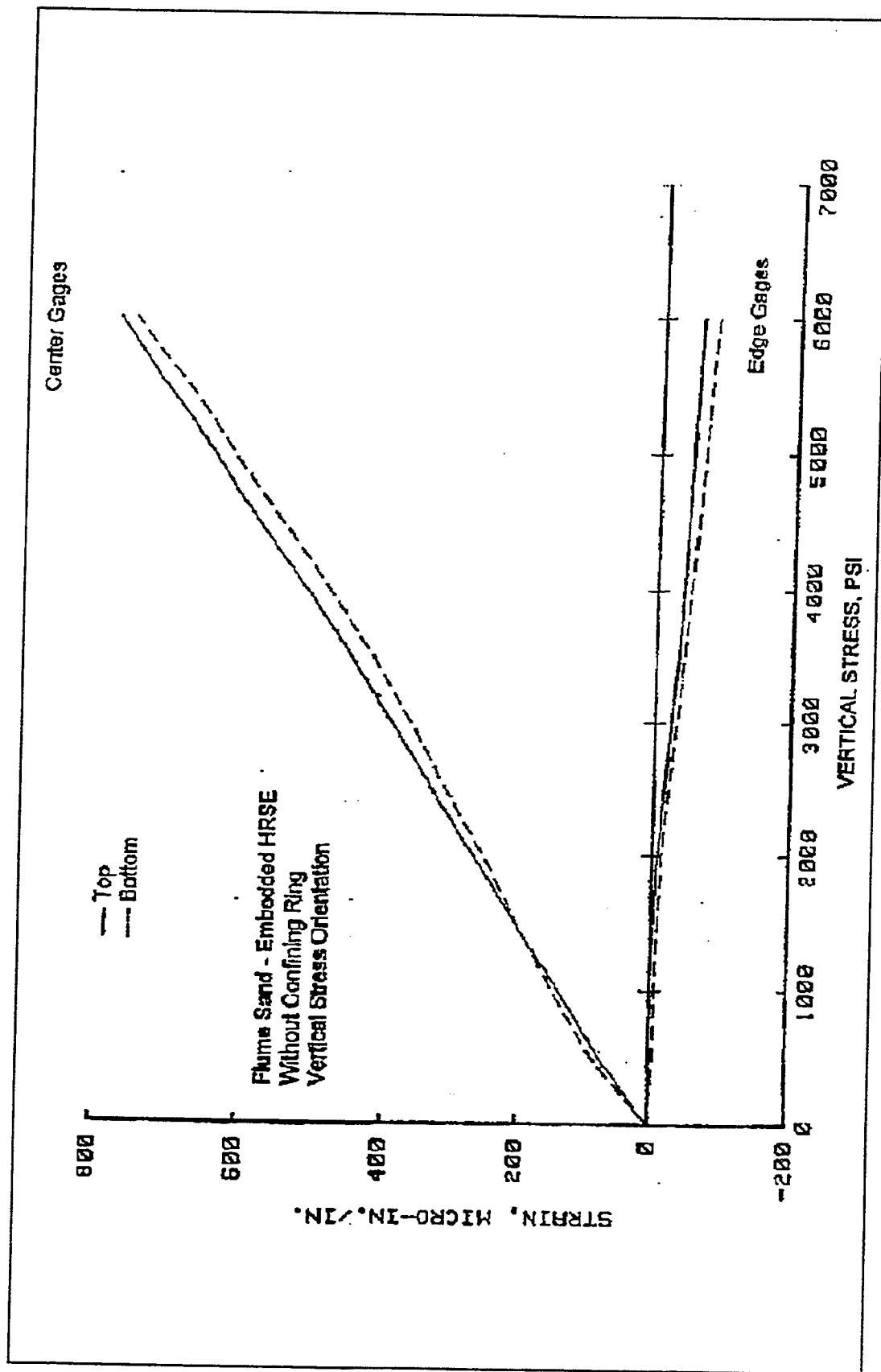


Figure 3.15. Individual strain gage measurements from flume sand-embedded calibration tests of a HRSE gage without a confining ring (oriented for vertical stress measurement)

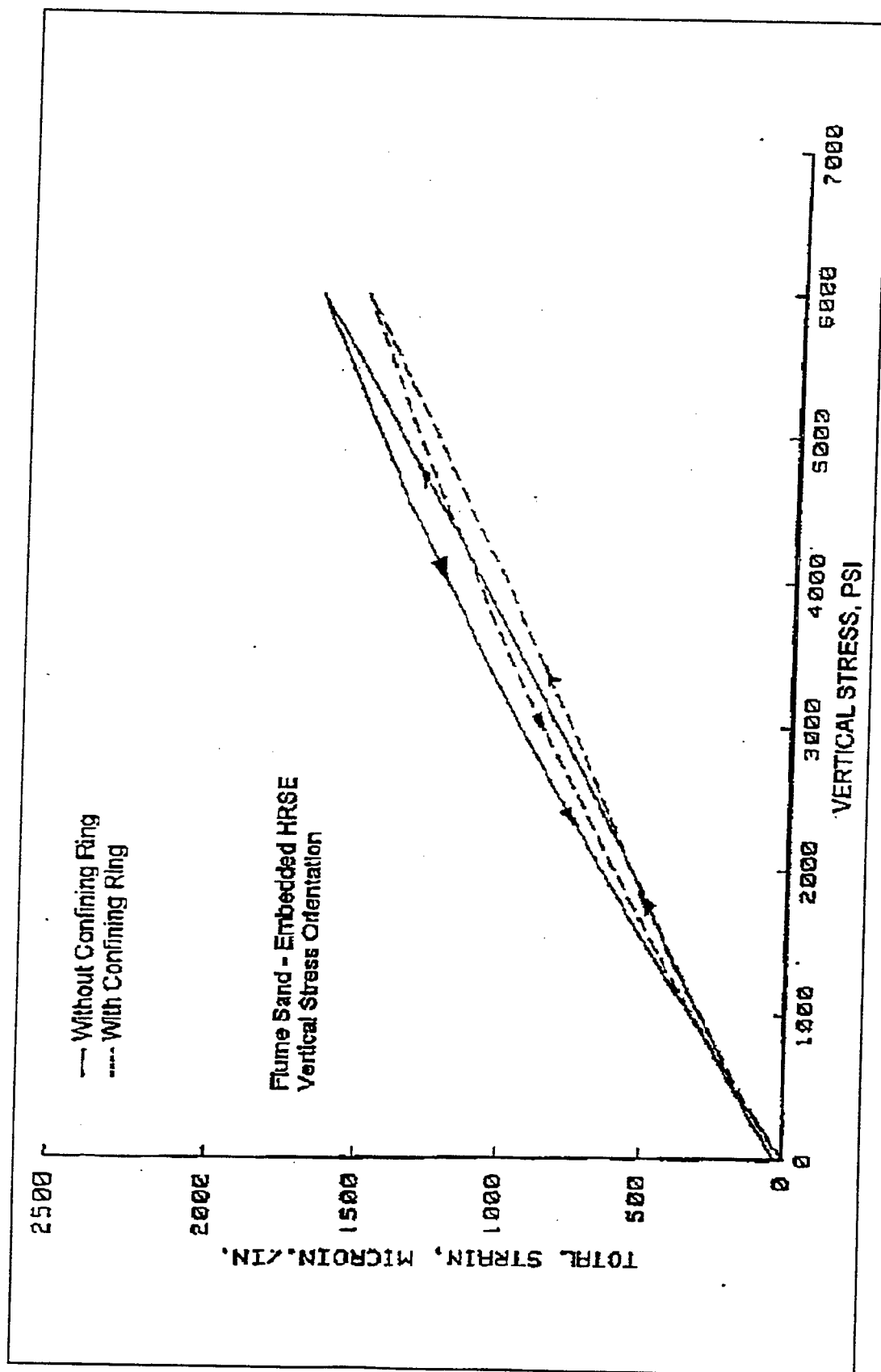


Figure 3.16. Comparison of total strain measurements on flume sand-embedded calibration tests of a HRSE gage with and without a confining ring (oriented for vertical stress measurements)

## 4 Summary

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Calibration tests were conducted on HRSE and LRSE stress gages immersed in oil and embedded in soil. Three soil types were used: (1) flume sand, SP, (2) Yuma clayey sand, SC, and (3) Vicksburg loess (silty clay), CL. Calibration tests were conducted in which the voltage output of the gage was recorded. These soil-embedded calibration test results may be used to reduce the raw stress gage data from field tests more accurately than can be achieved using the standard oil-immersed calibrations. Stress gage calibration tests were also conducted in which the strain output from each of the four individual strain gages in the wheatstone bridge were recorded. The gages were oriented for both vertical and horizontal stress measurements, and calibration tests were conducted on the gages with and without confining rings. The results of these strain output tests can be directly compared with the results from finite element gage-simulation calculations.

A total of 70 calibration tests were conducted with gages immersed in oil. The load-unload curves from the hydrostatic calibrations in which voltage was recorded displayed linear elastic behavior. Response of the LRSE gage was essentially linear elastic for hydrostatic calibrations in which strain was the recorded output. But while the loading portion of the corresponding HRSE calibrations was essentially linear, the unloading portion was slightly nonlinear, resulting in some hysteresis in the load-unload cycle. The calibration constant or  $C_a$  values for HRSE gages were typically four times greater than the values obtained for LRSE gages.

Significant differences are seen in the results of the 187 soil-embedded calibrations. These differences were determined by gage type, soil type, and gage orientation. A slightly nonlinear loading curve typified all soil-embedded calibrations. The slope of the loading curve was dependent upon gage type and soil type. Major differences in response due to gage type and soil type were seen in the unloading curves from the soil-embedded calibration tests; hysteresis was a dominant characteristic of all load-unload cycles. The magnitude of the hysteresis was much greater for LRSE gages than for HRSE gages. LRSE gages calibrated in the Yuma clayey sand displayed the most hysteresis, whereas HRSE gages calibrated in Vicksburg loess (silty clay) were characterized by the least amount of hysteresis.

Reloading paths for all soil-embedded calibration tests were similar, i.e., the paths were linear from the beginning point of reloading to the previous point of maximum applied pressure. Neither soil type, gage type, nor gage orientation had a detectable effect on the reloading path.

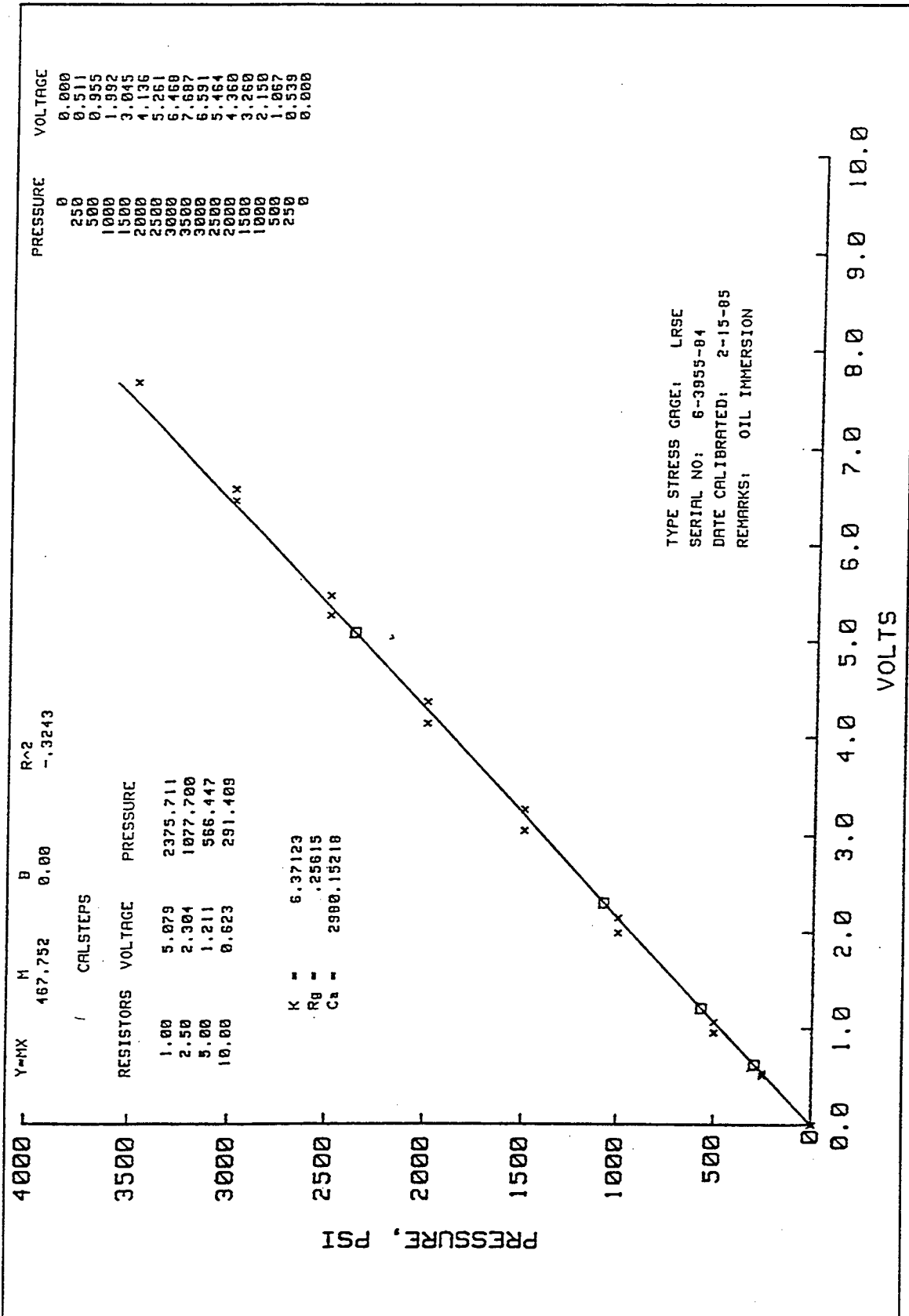
The presence of a confining ring caused significant differences in response of the HRSE gage. Strain gages located on the edges of the HRSE gage diaphragms recorded tensile strains when a confining ring was present, and compressive strains when the confining ring was absent. The confining ring did not affect the results of a LRSE gage when placed for vertical stress measurement; however, when a LRSE gage was oriented for horizontal stress measurement, the total strain for the gages with the confining ring was consistently higher during both loading and unloading than for the gages without the confining ring.



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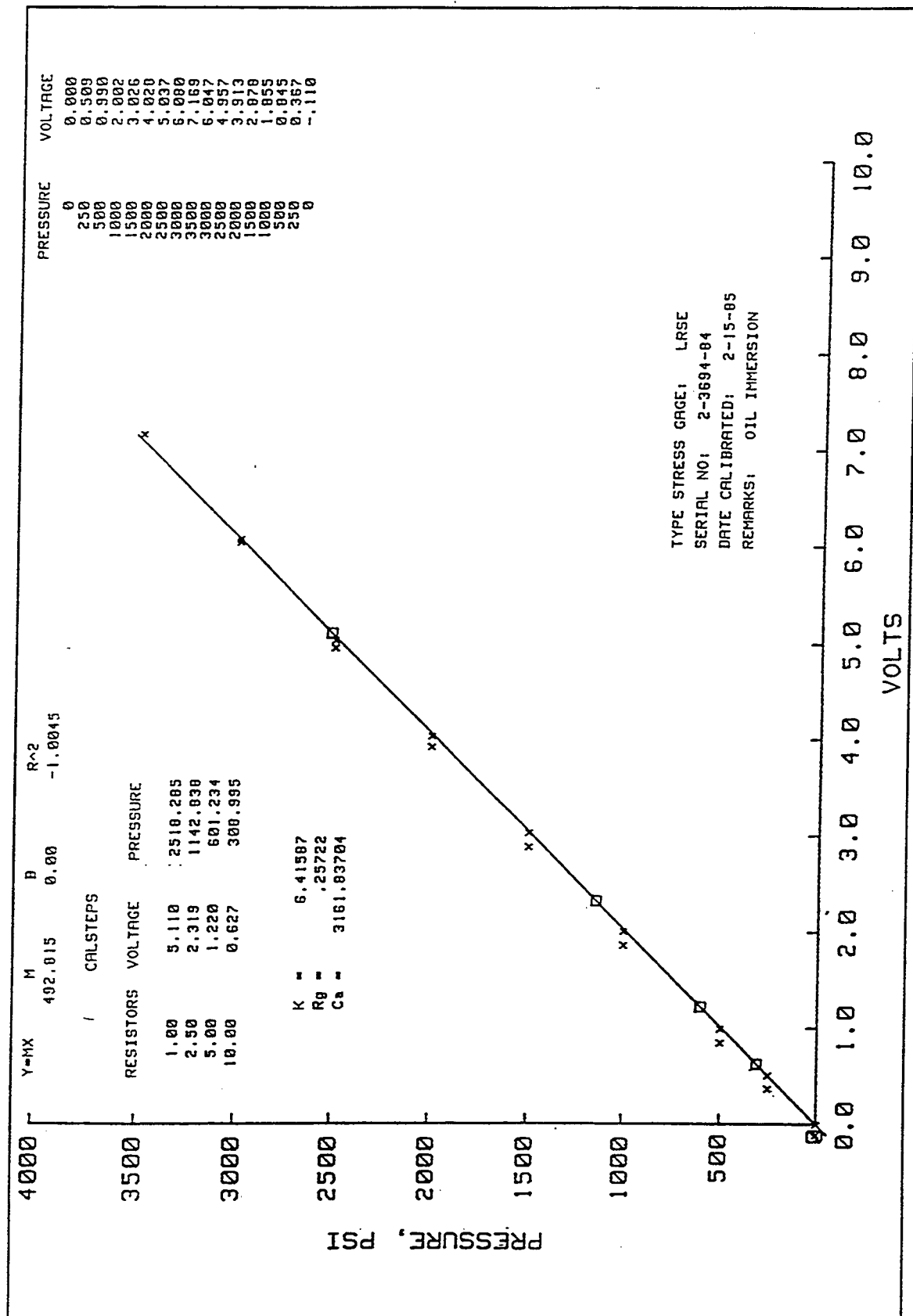
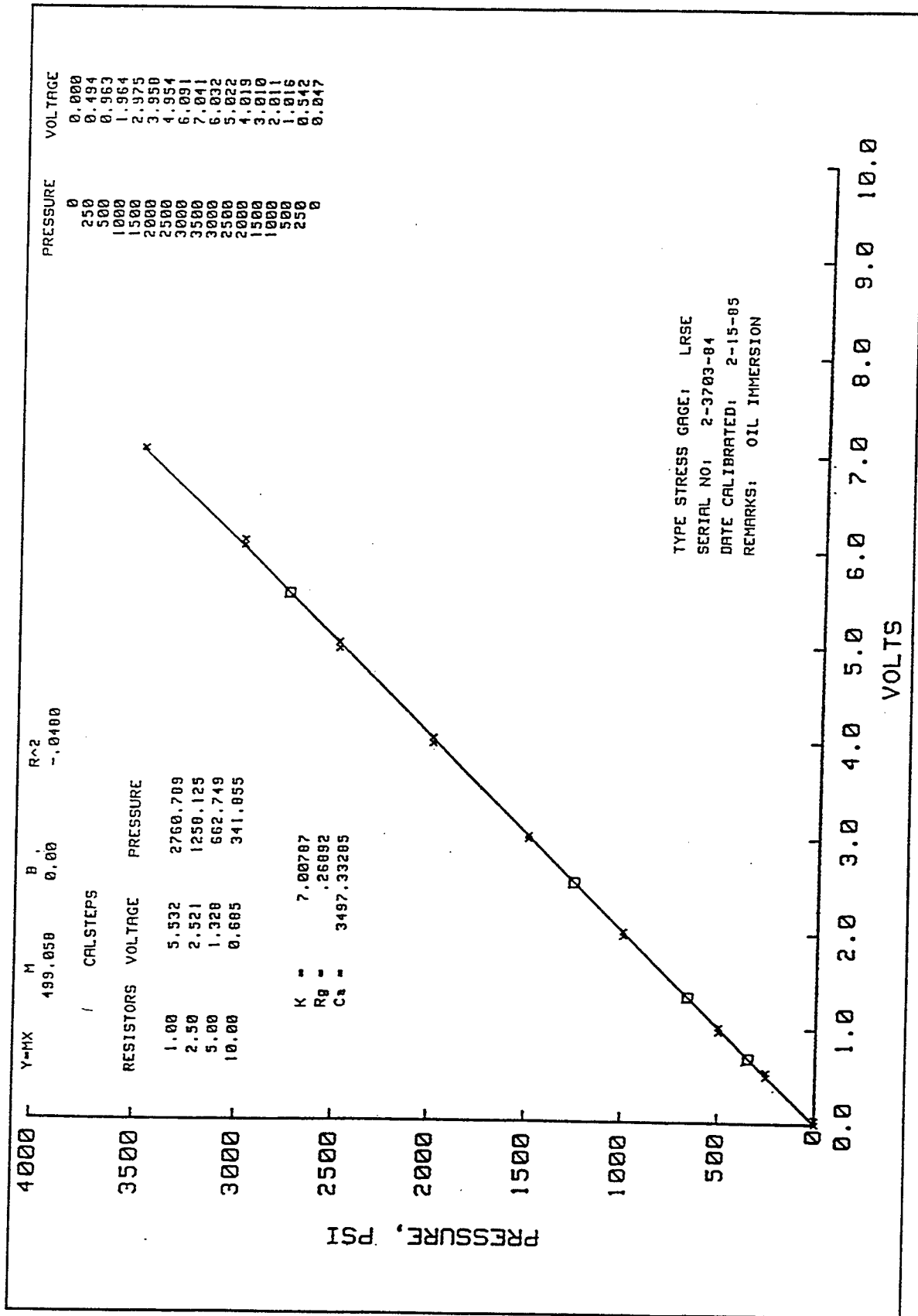
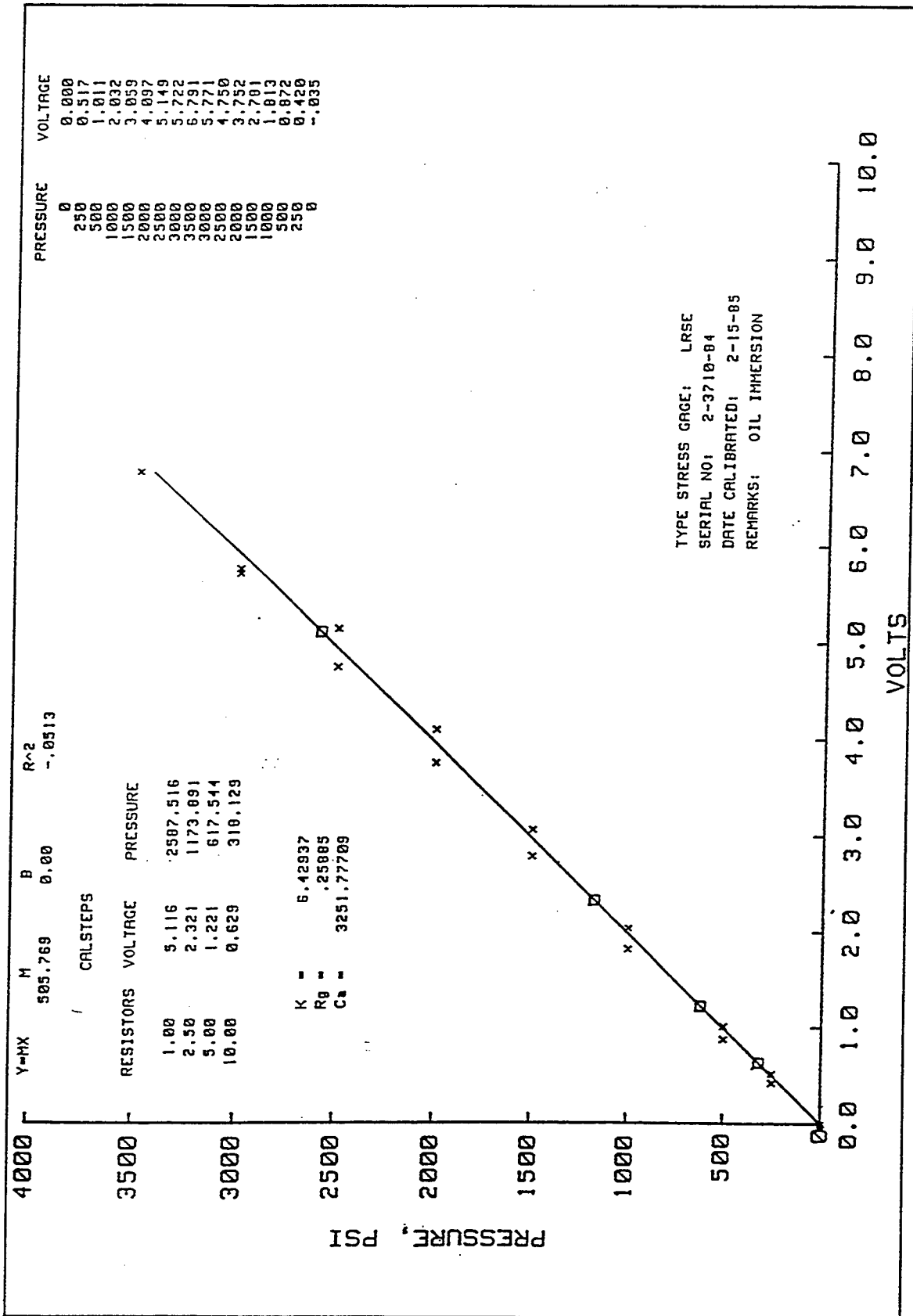


Plate 4





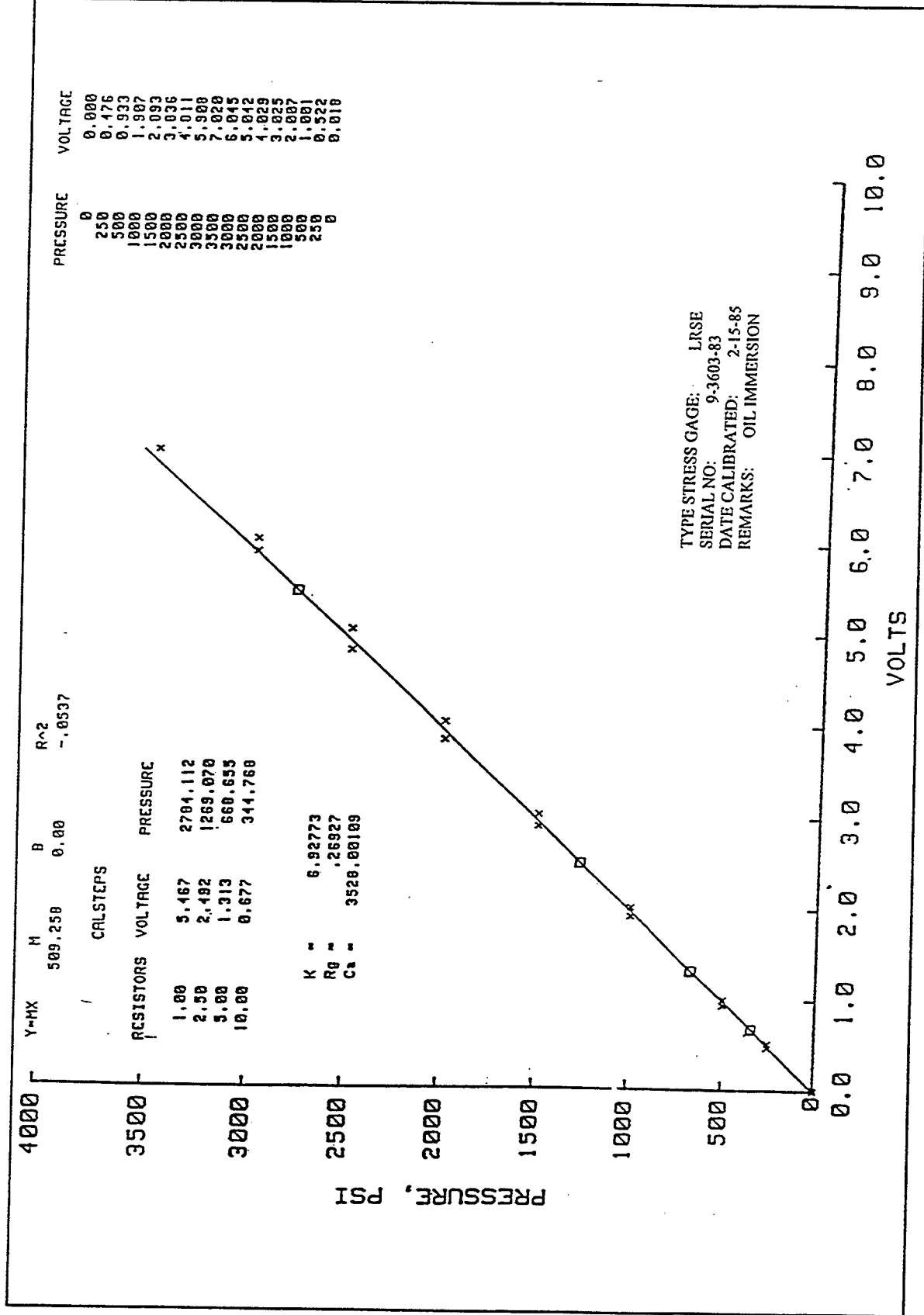


Plate 6

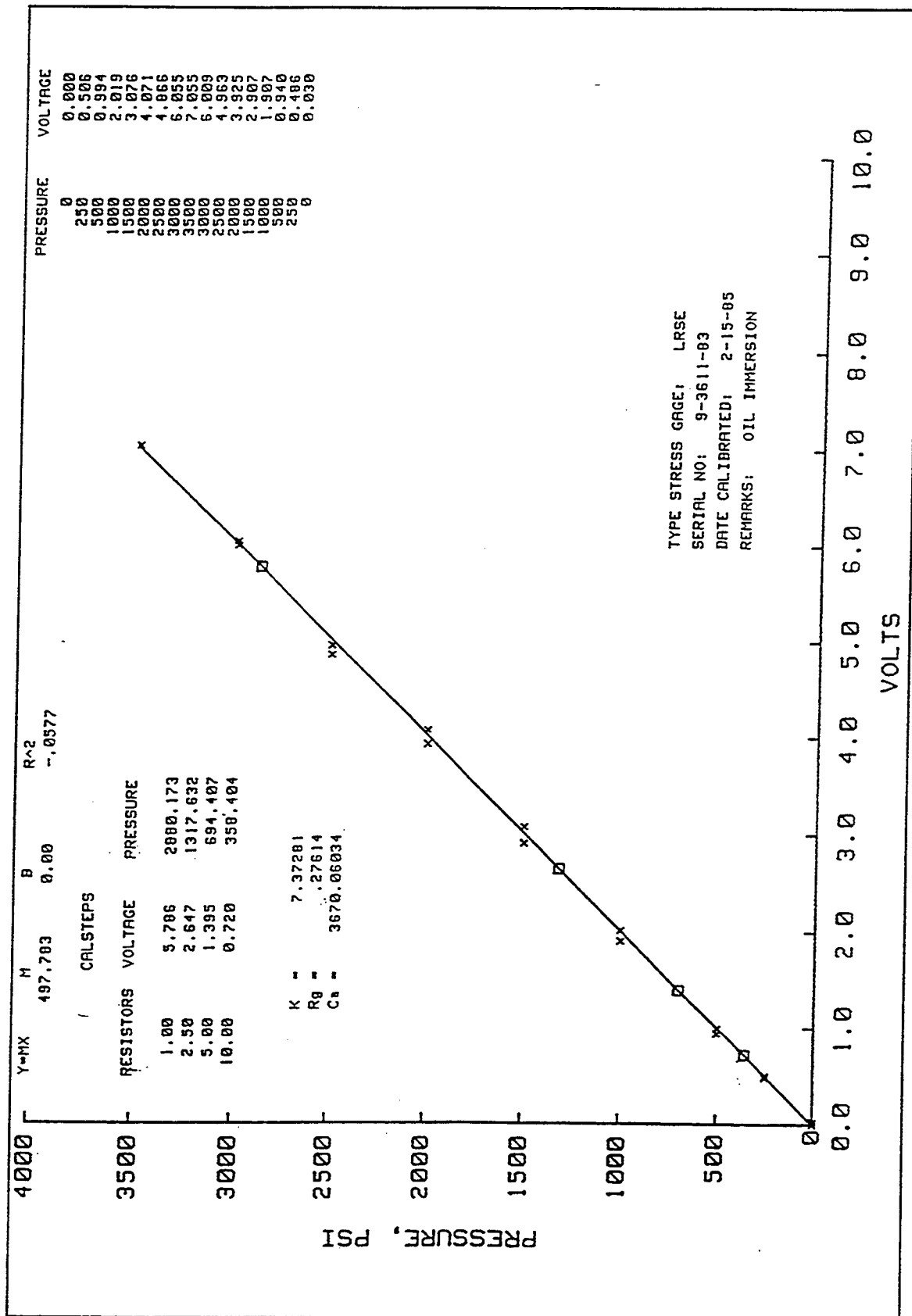
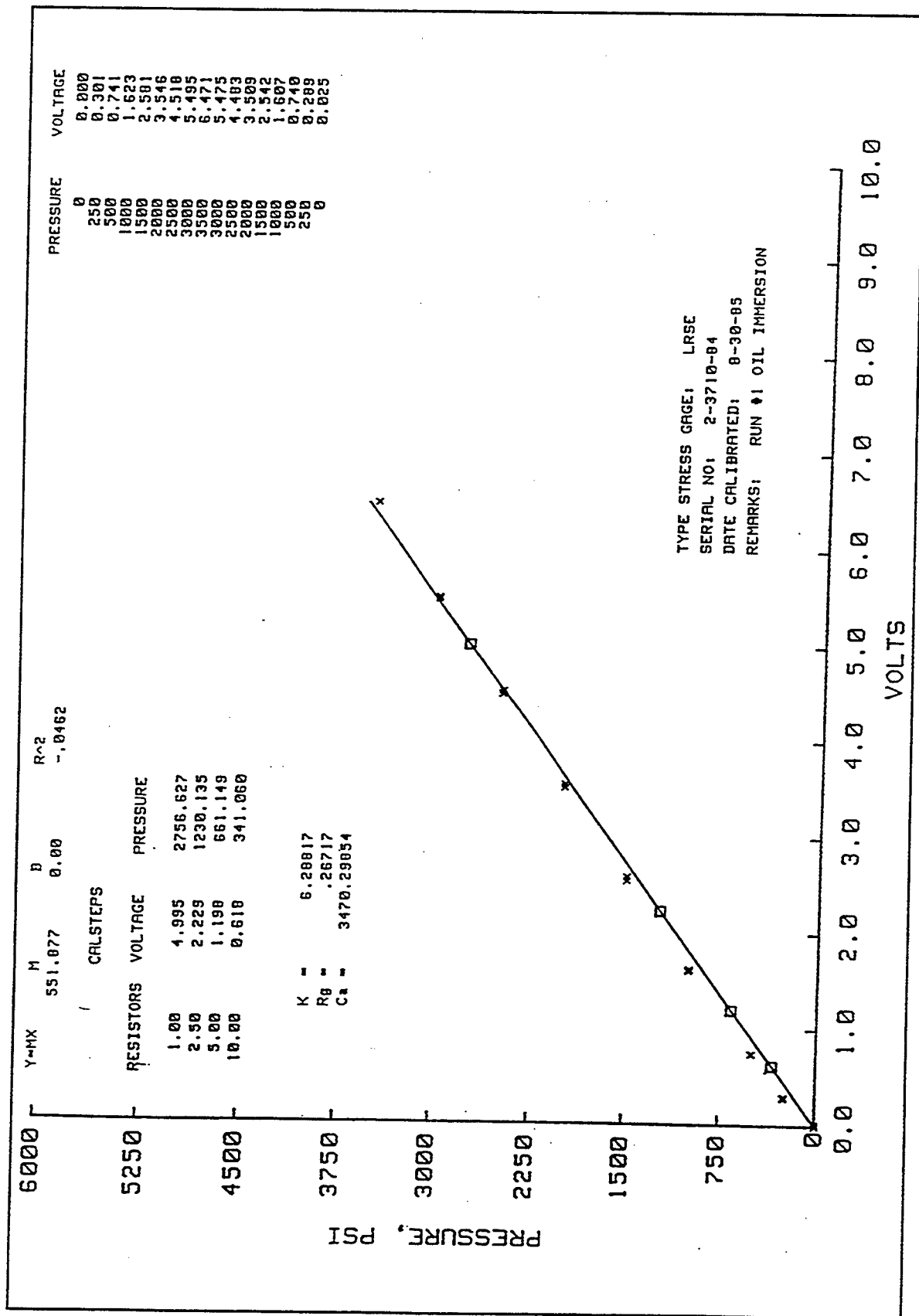
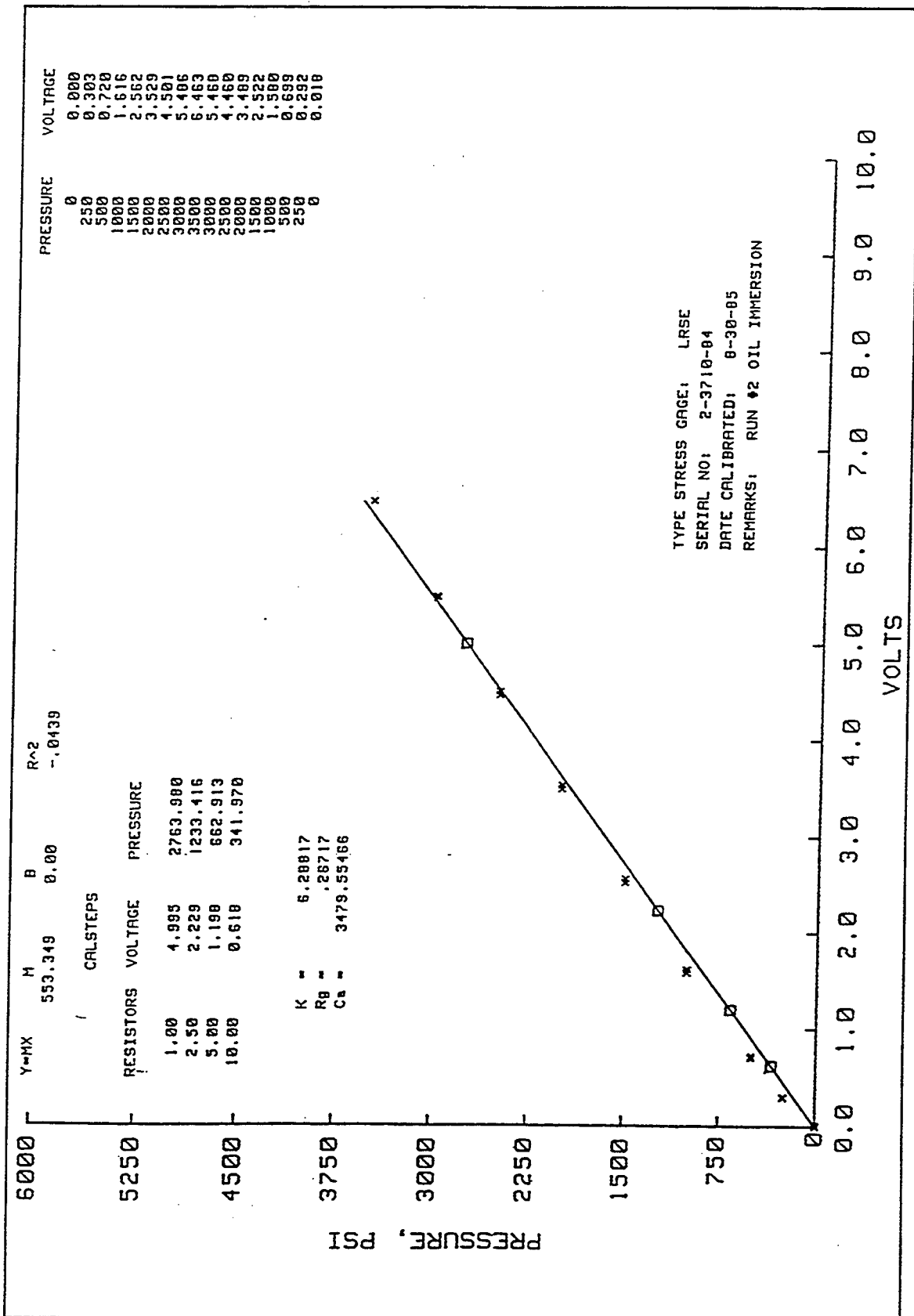
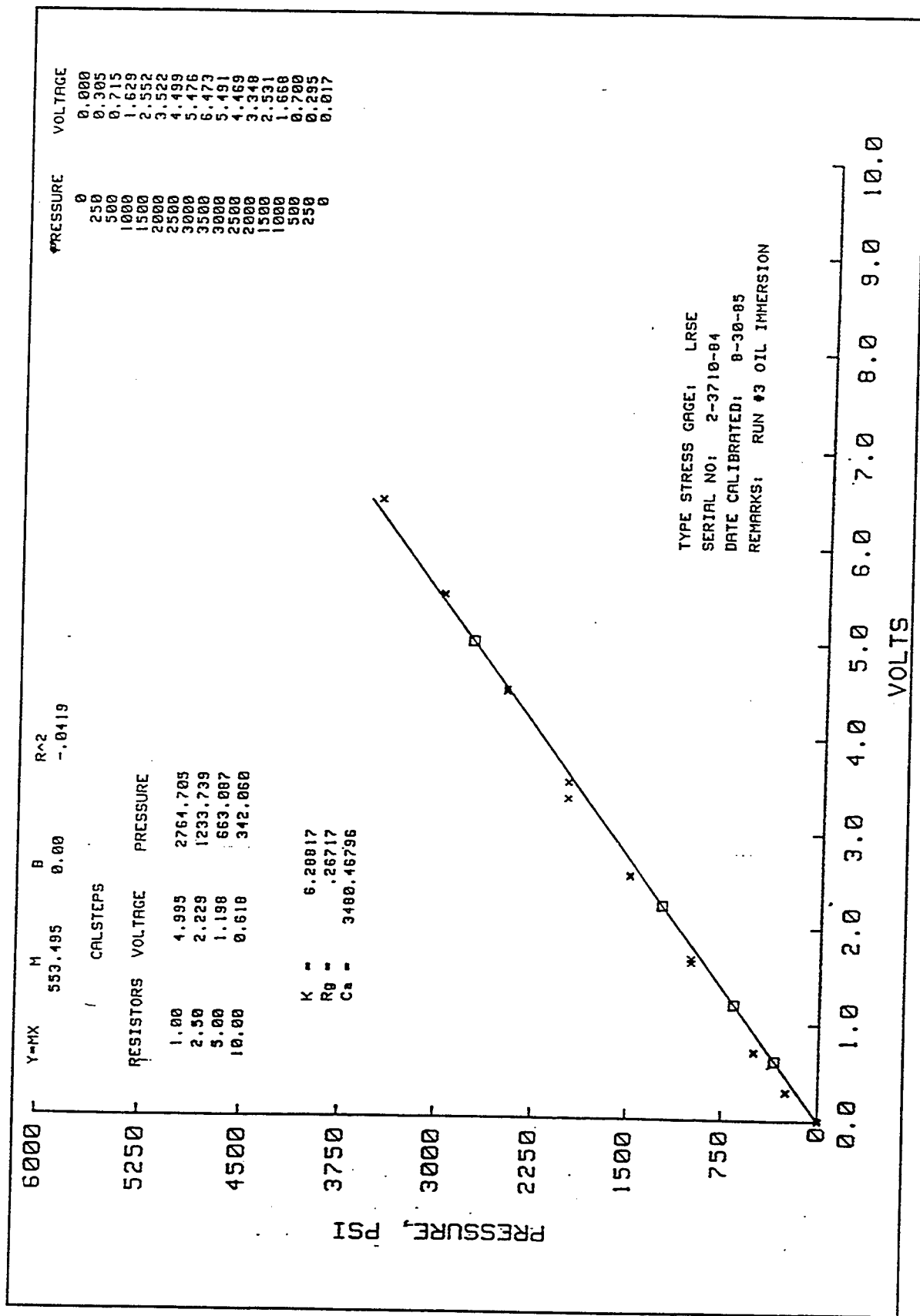


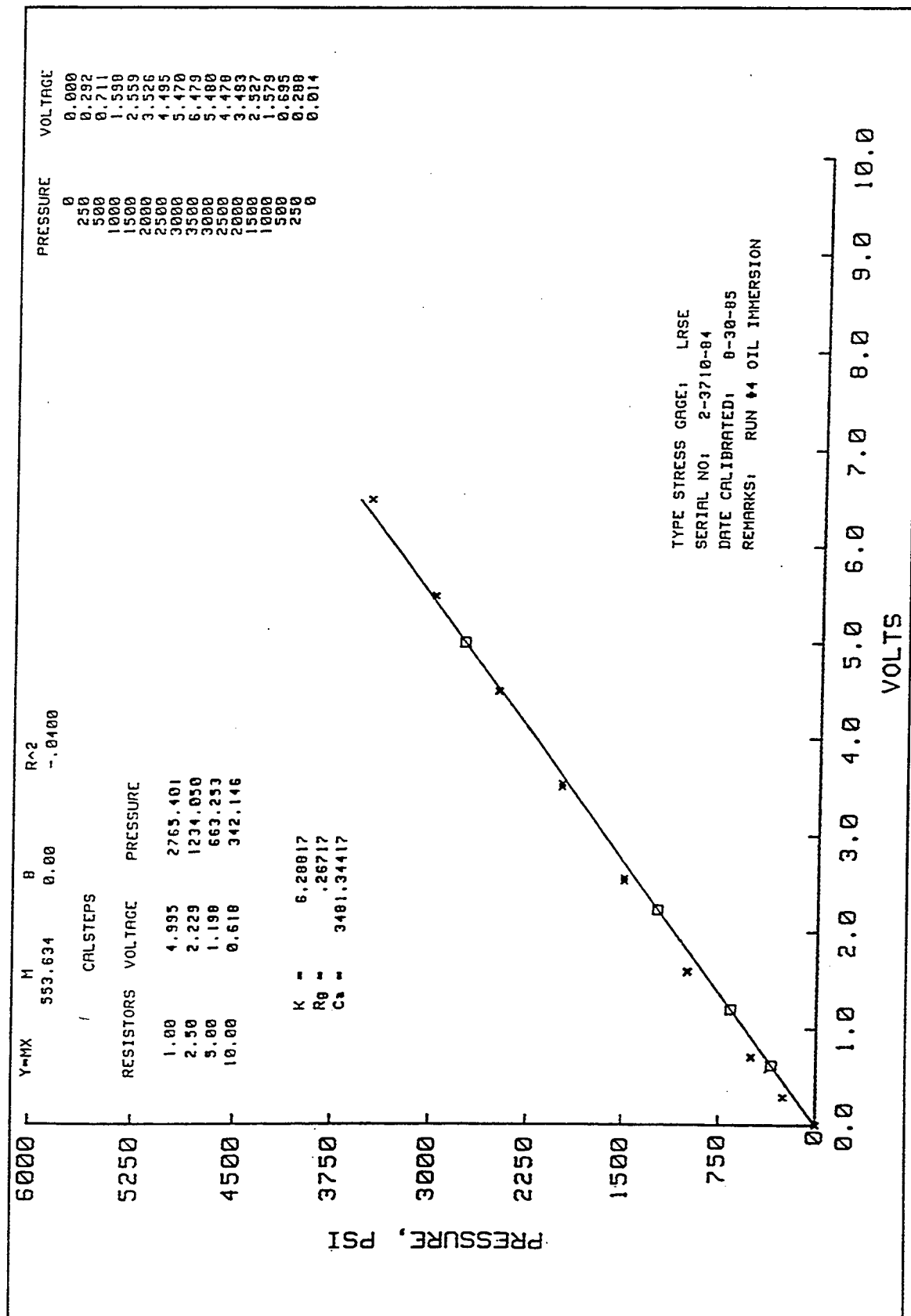


Plate 8









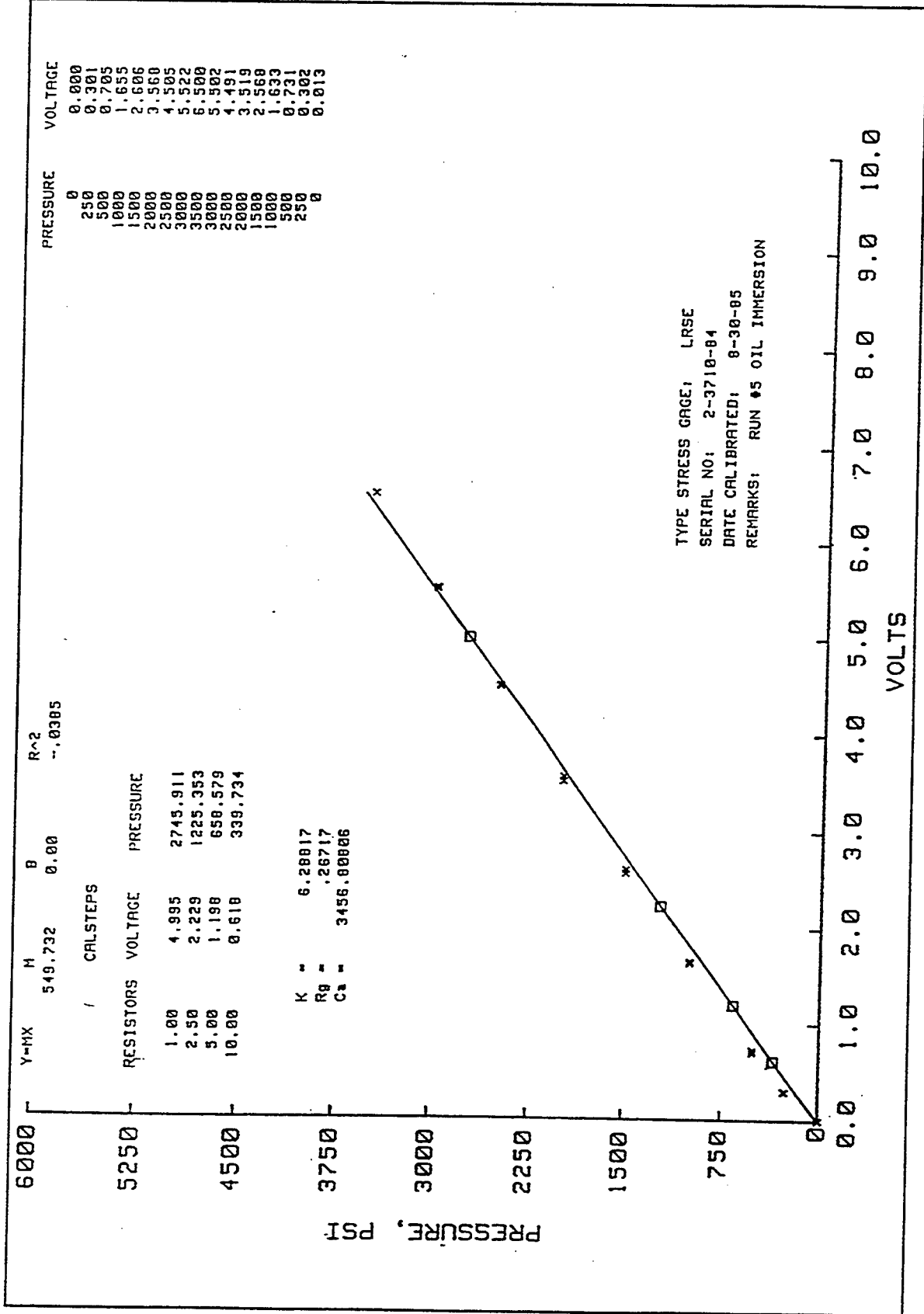
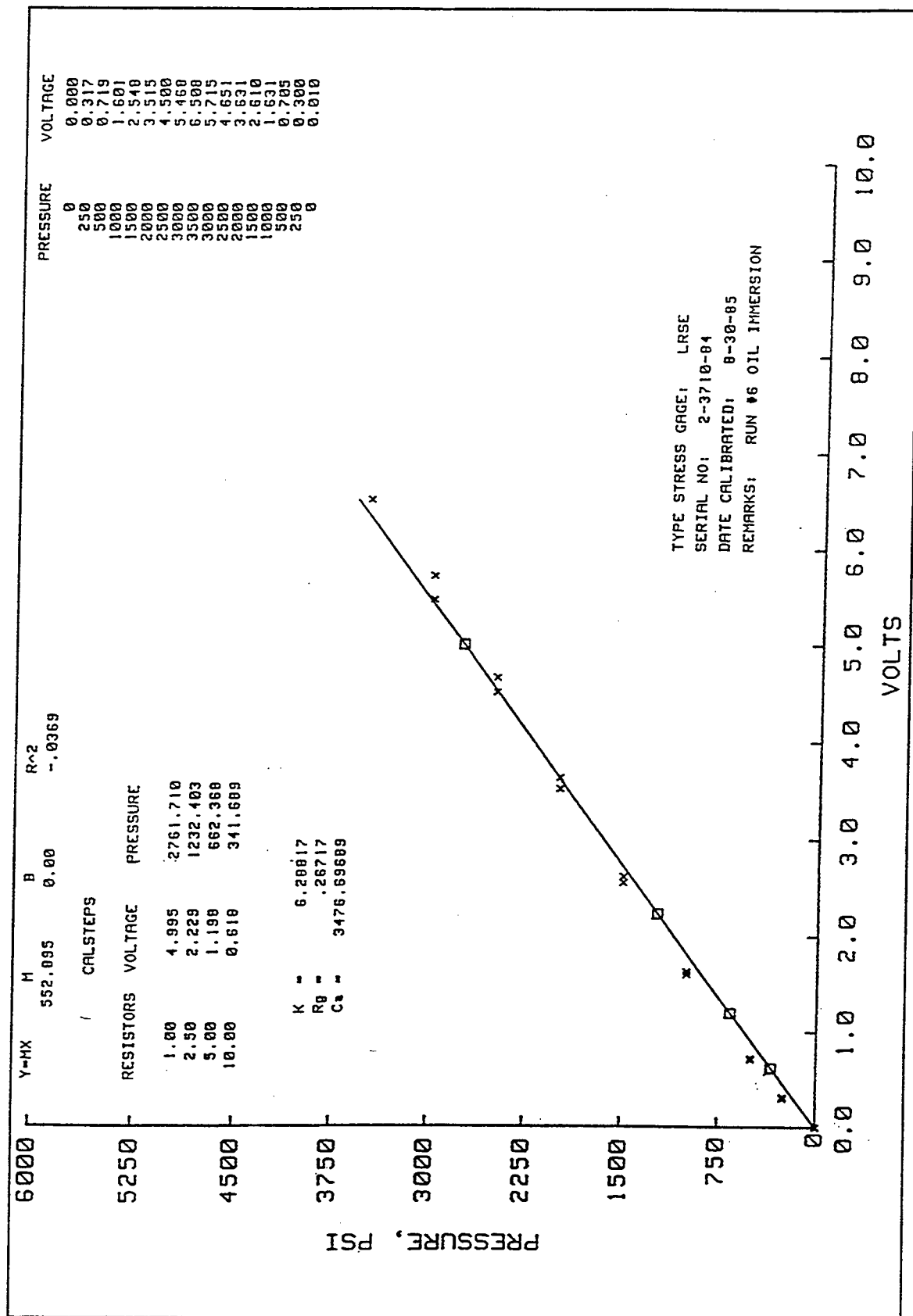
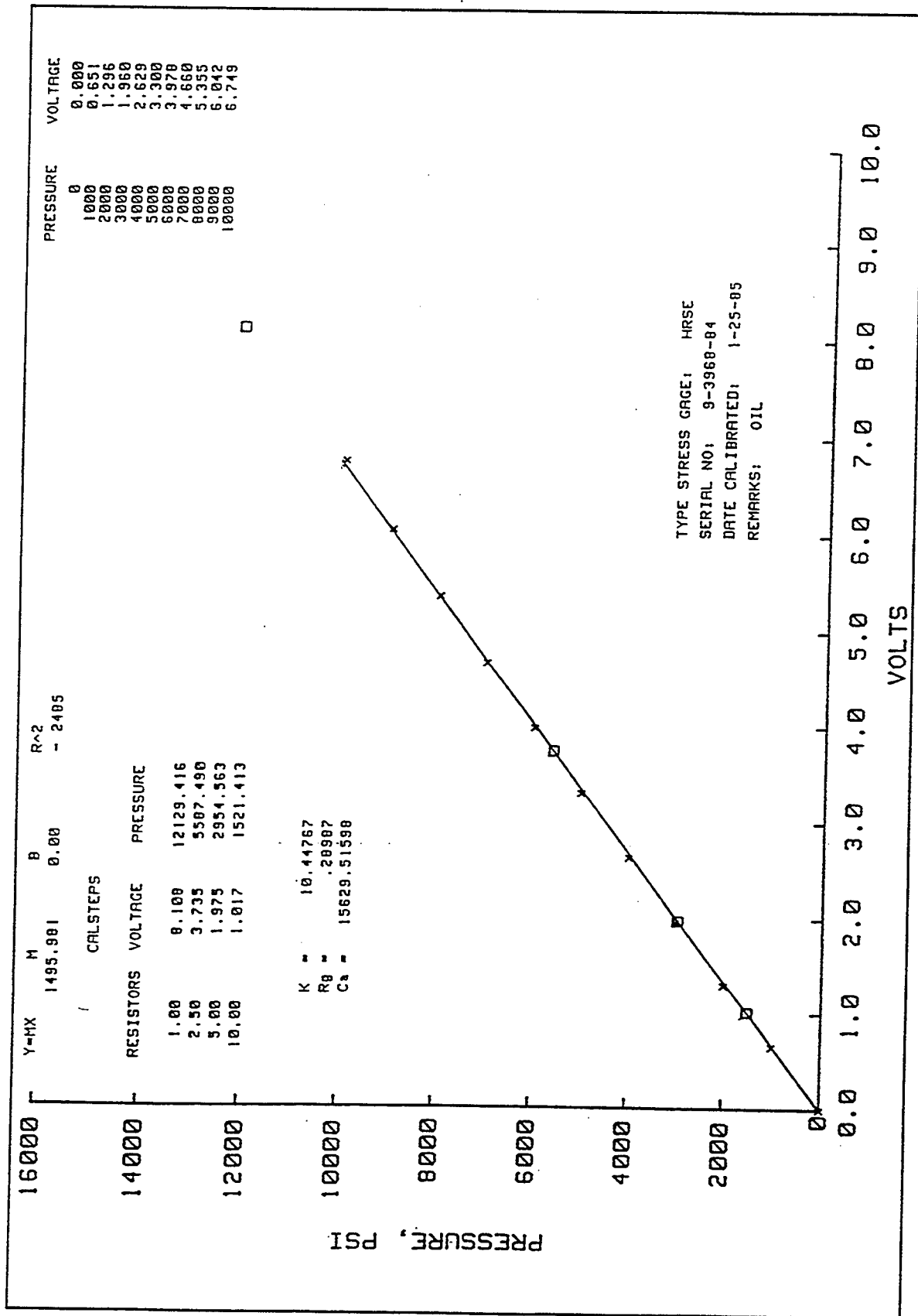
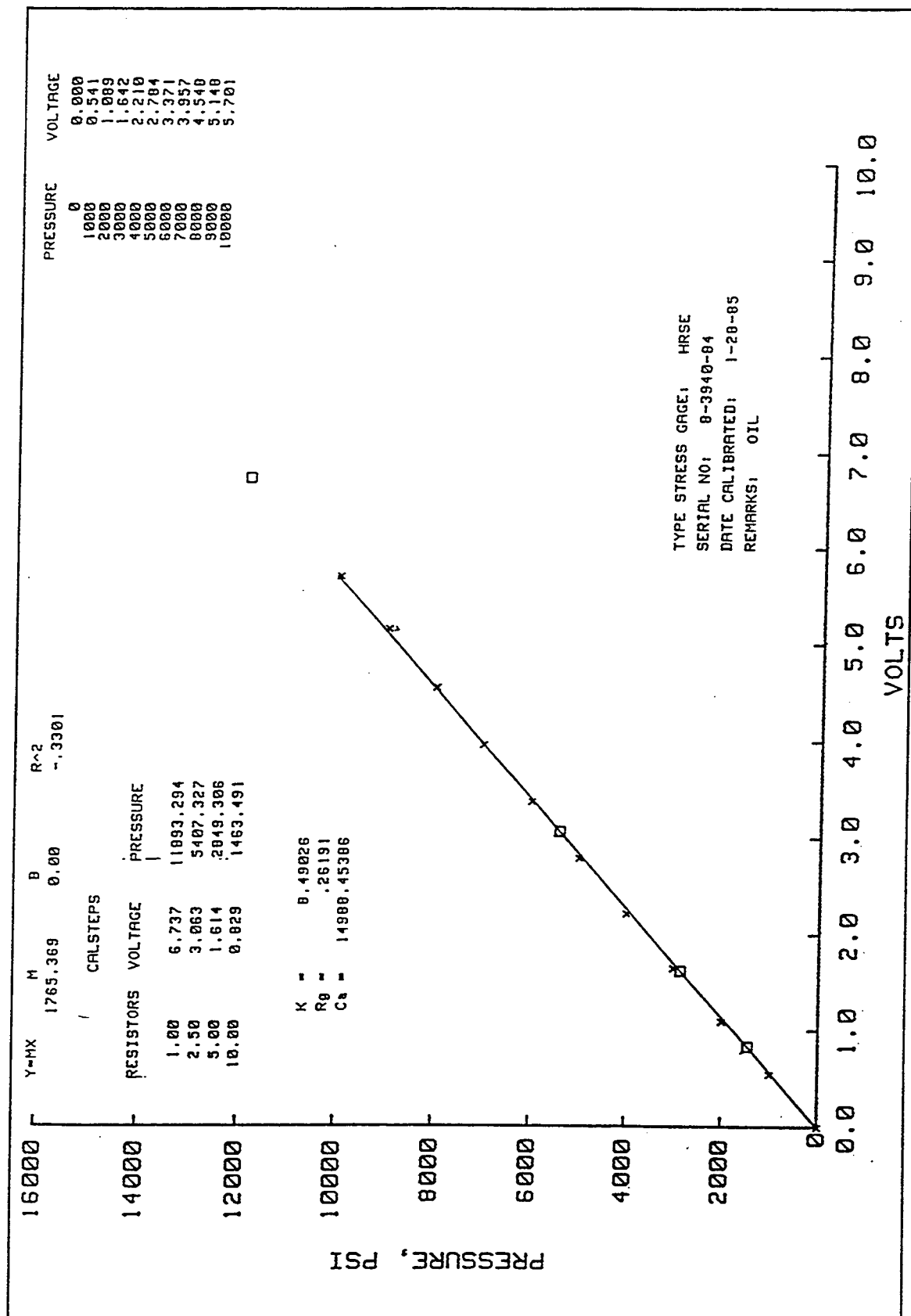


Plate 12









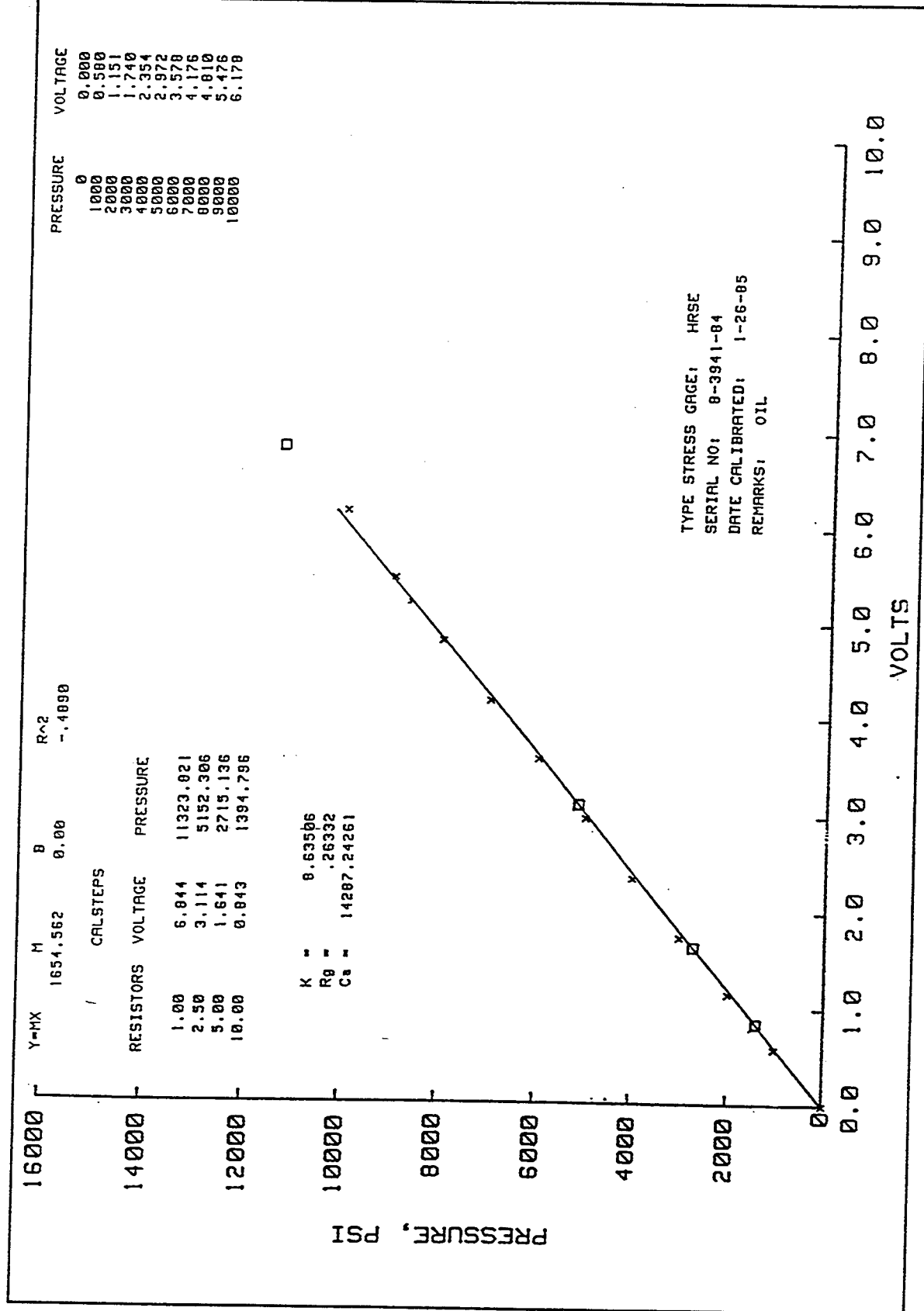
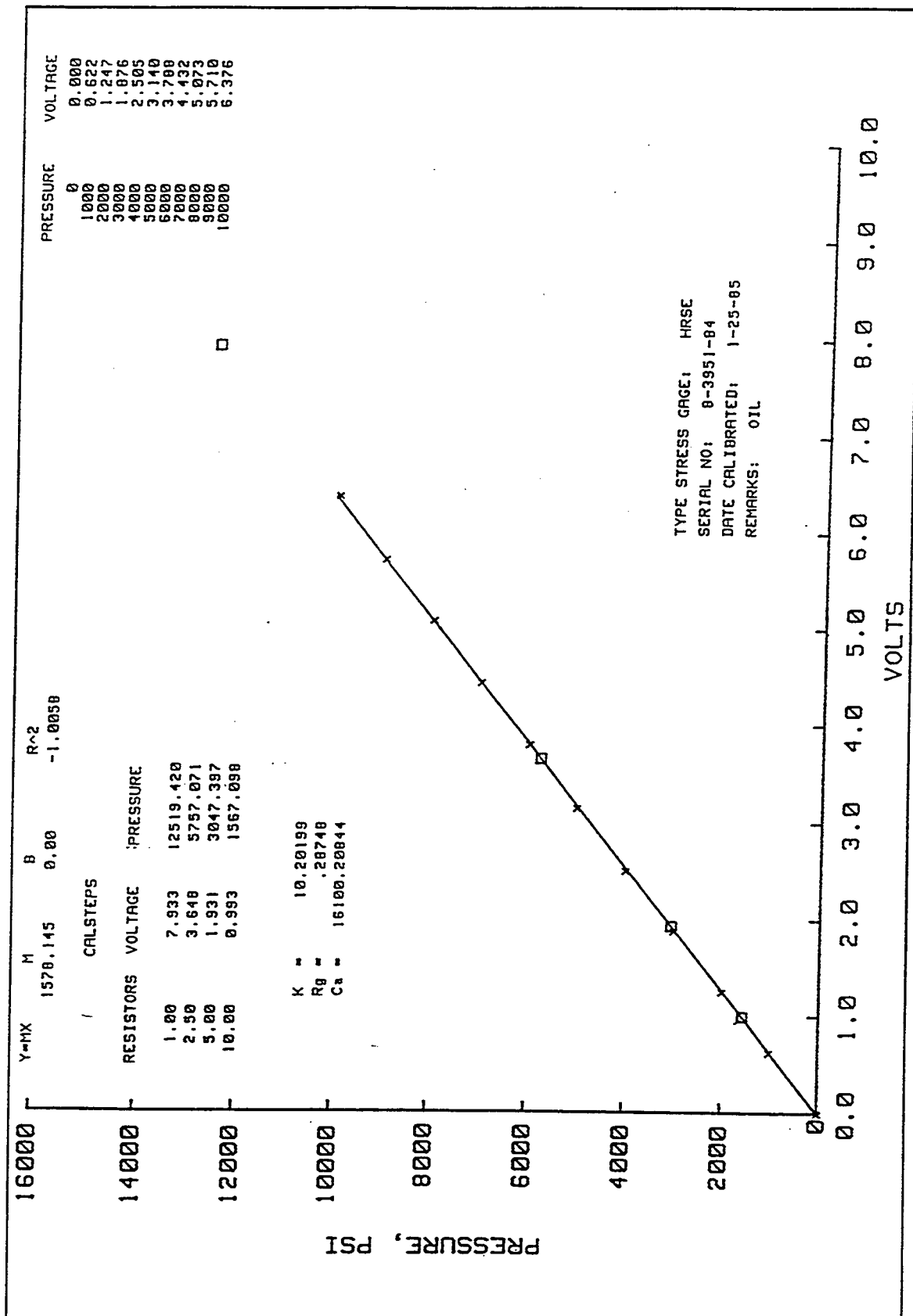


Plate 16



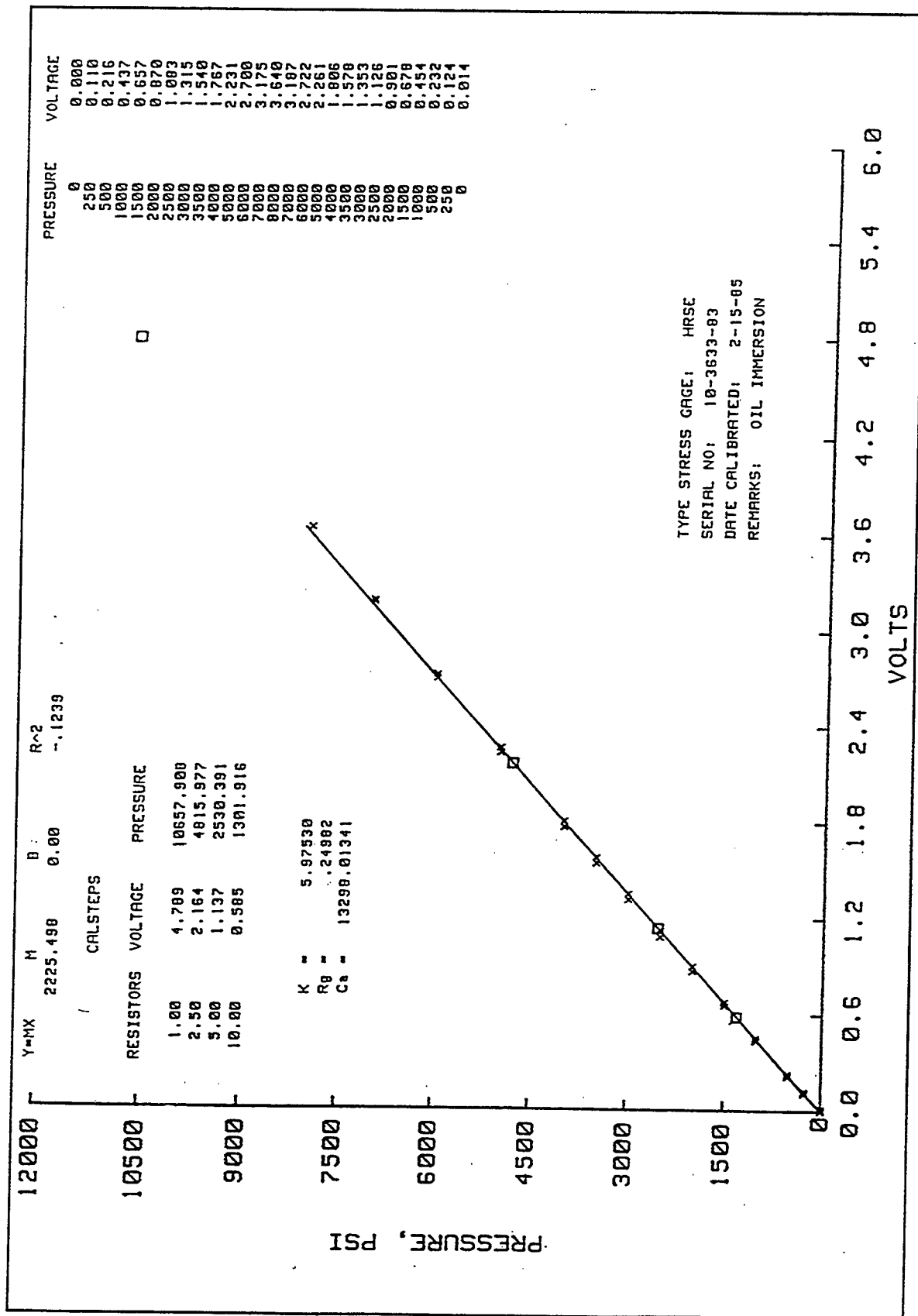
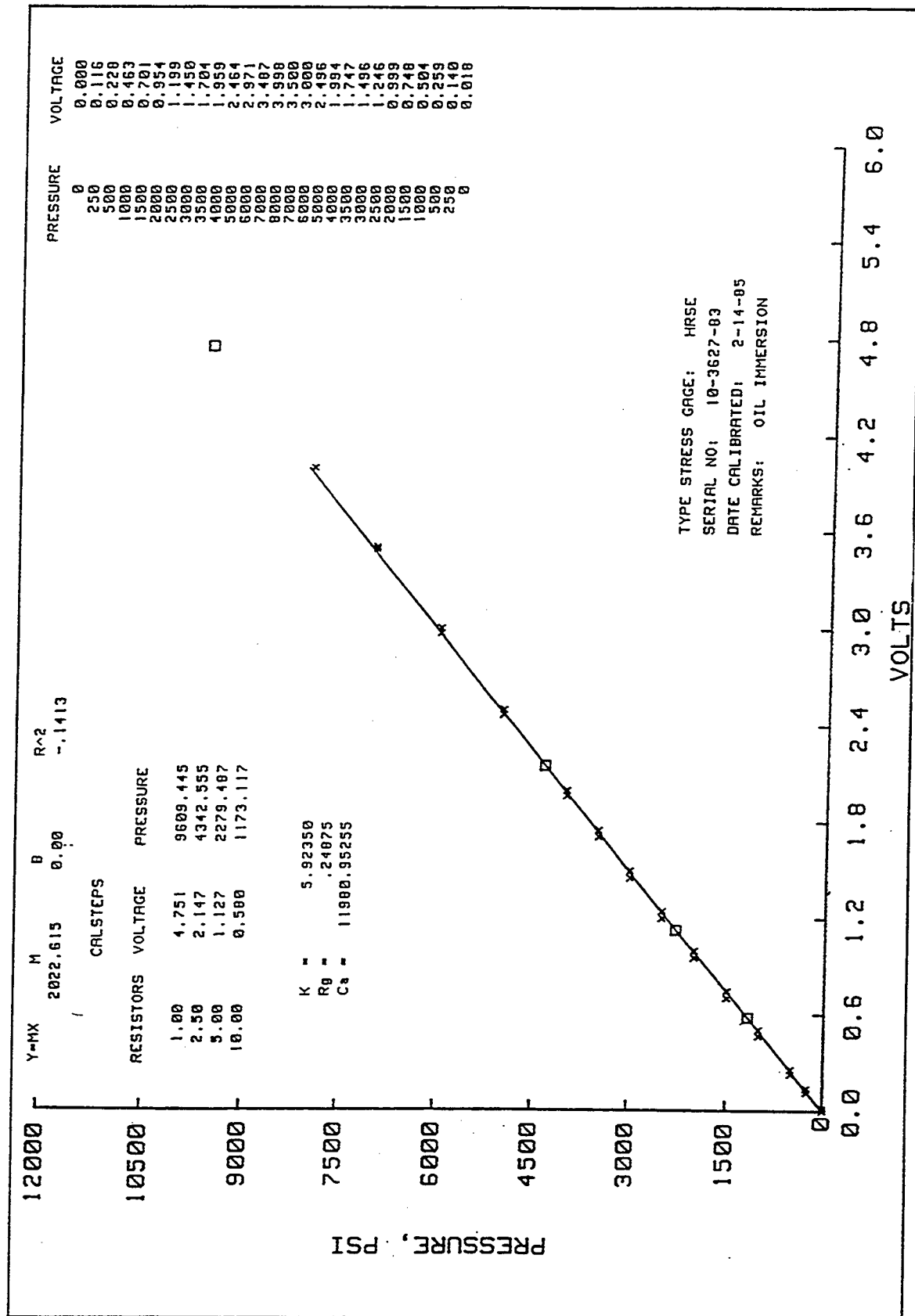
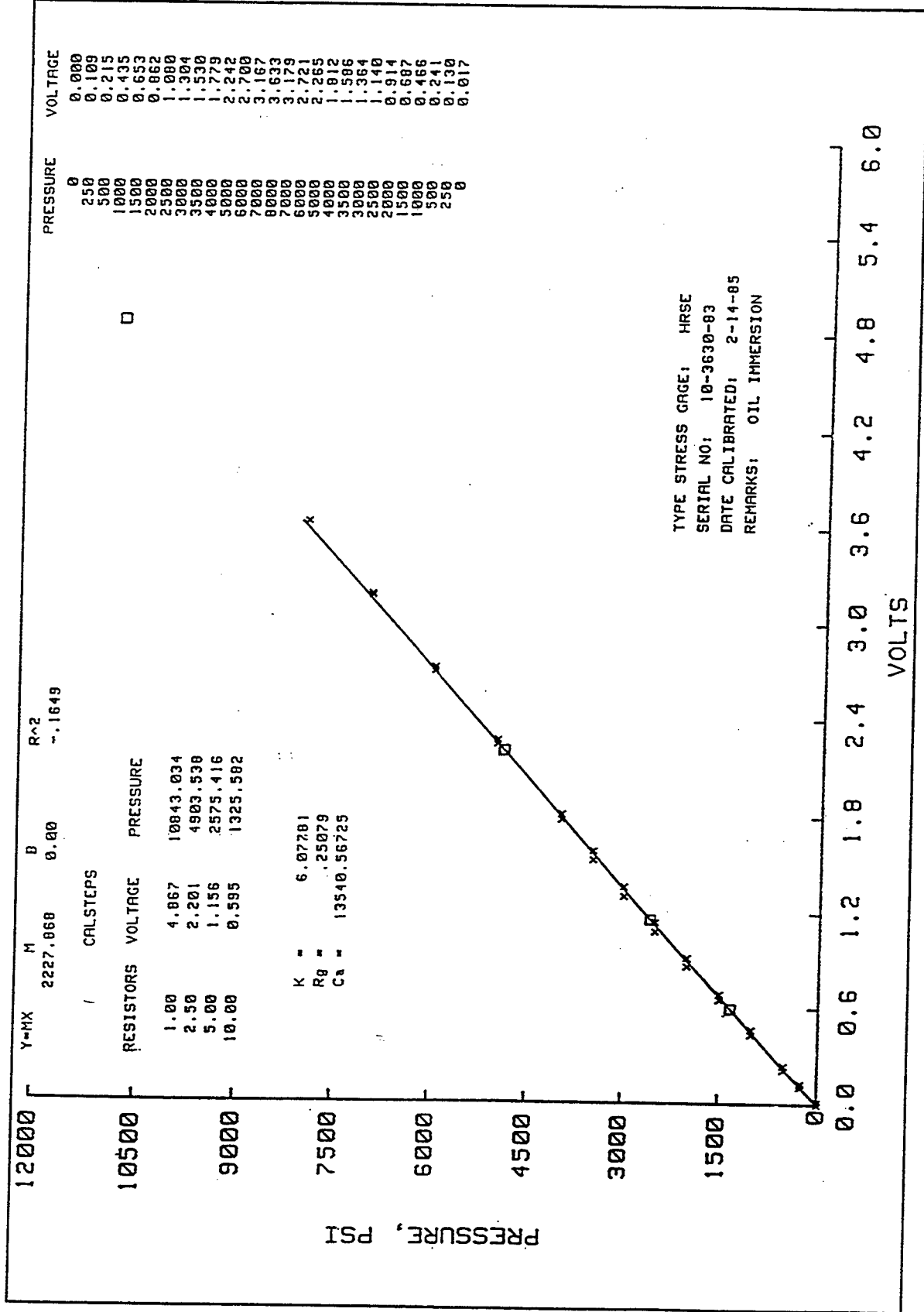
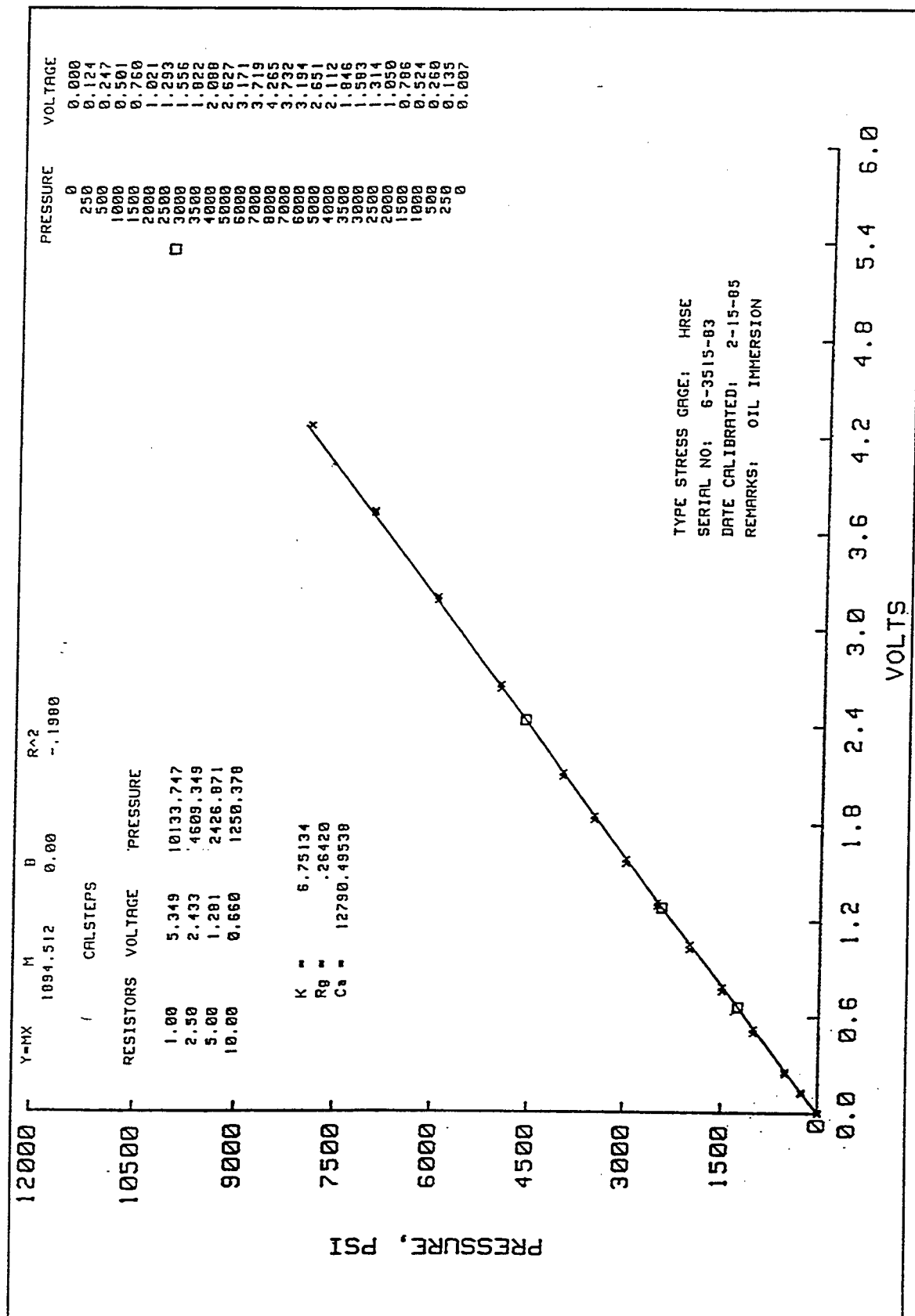
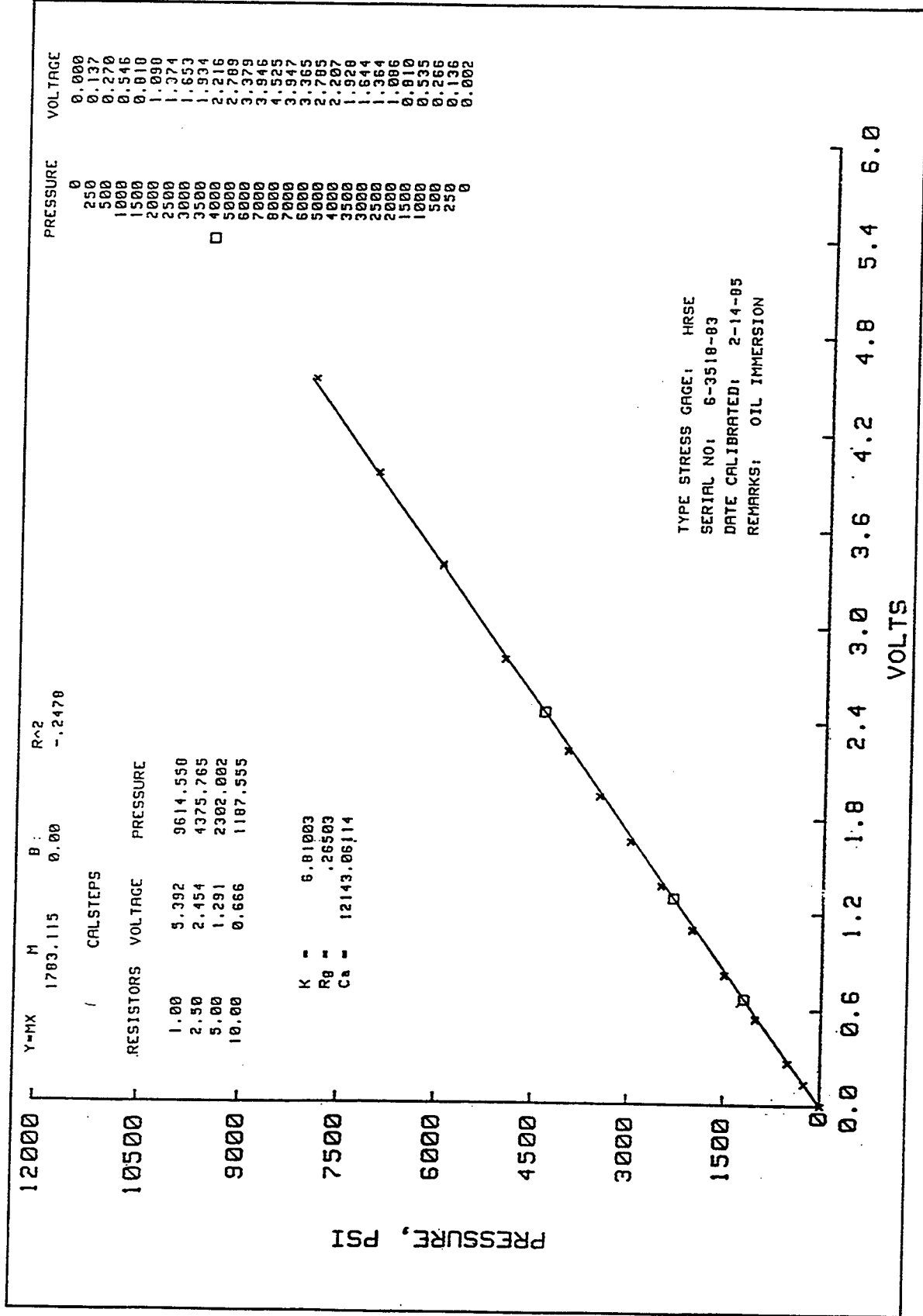


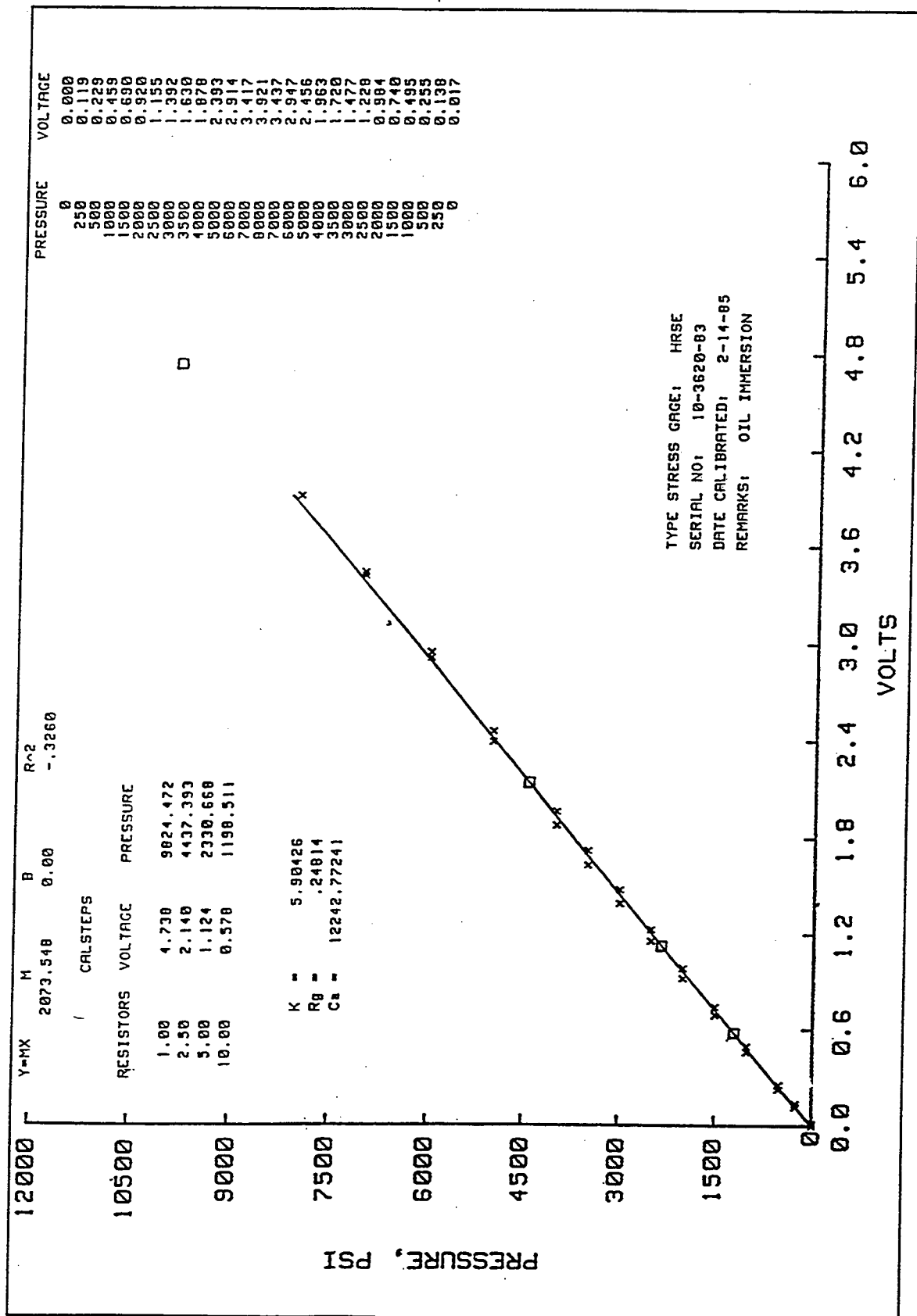
Plate 18













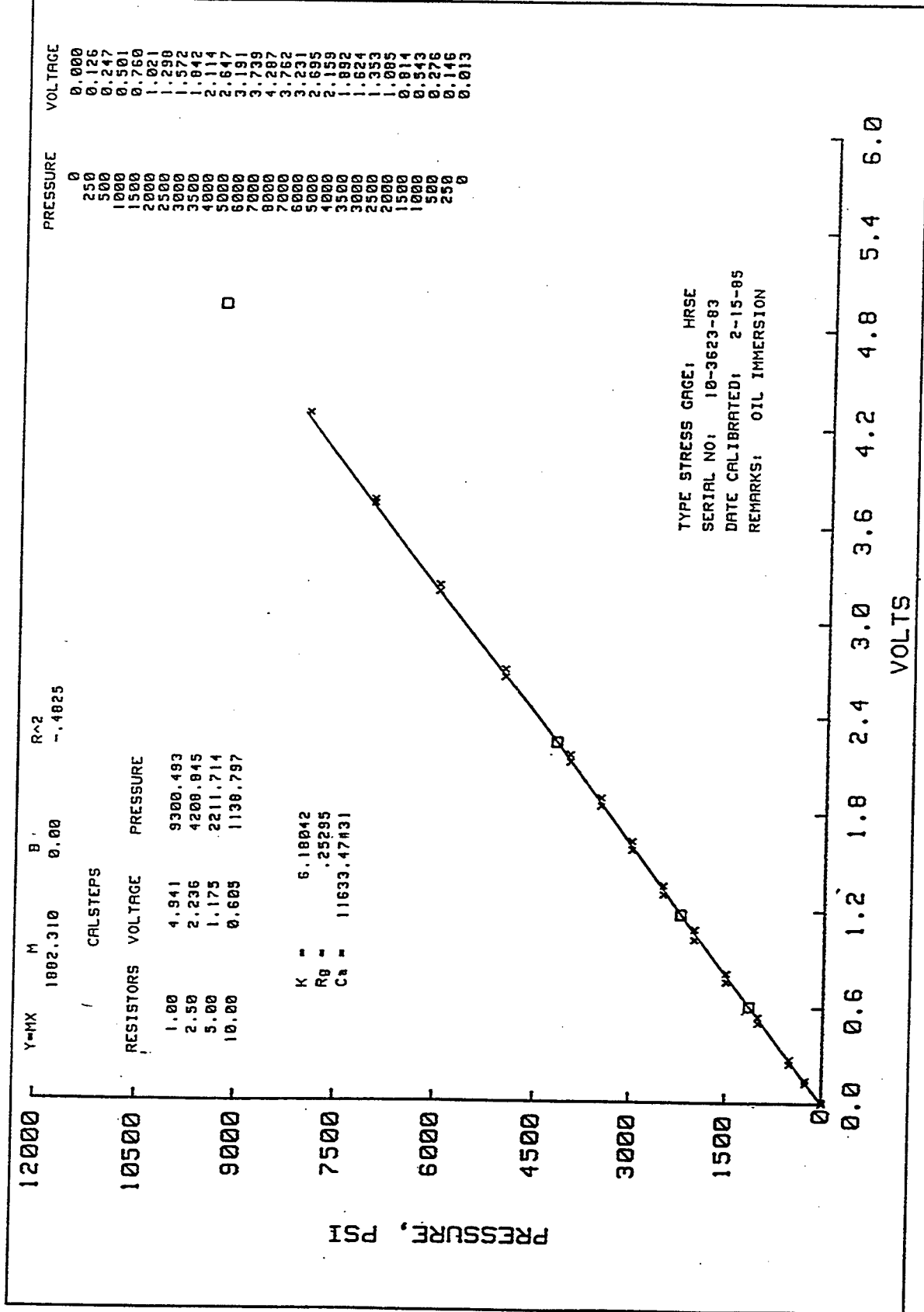
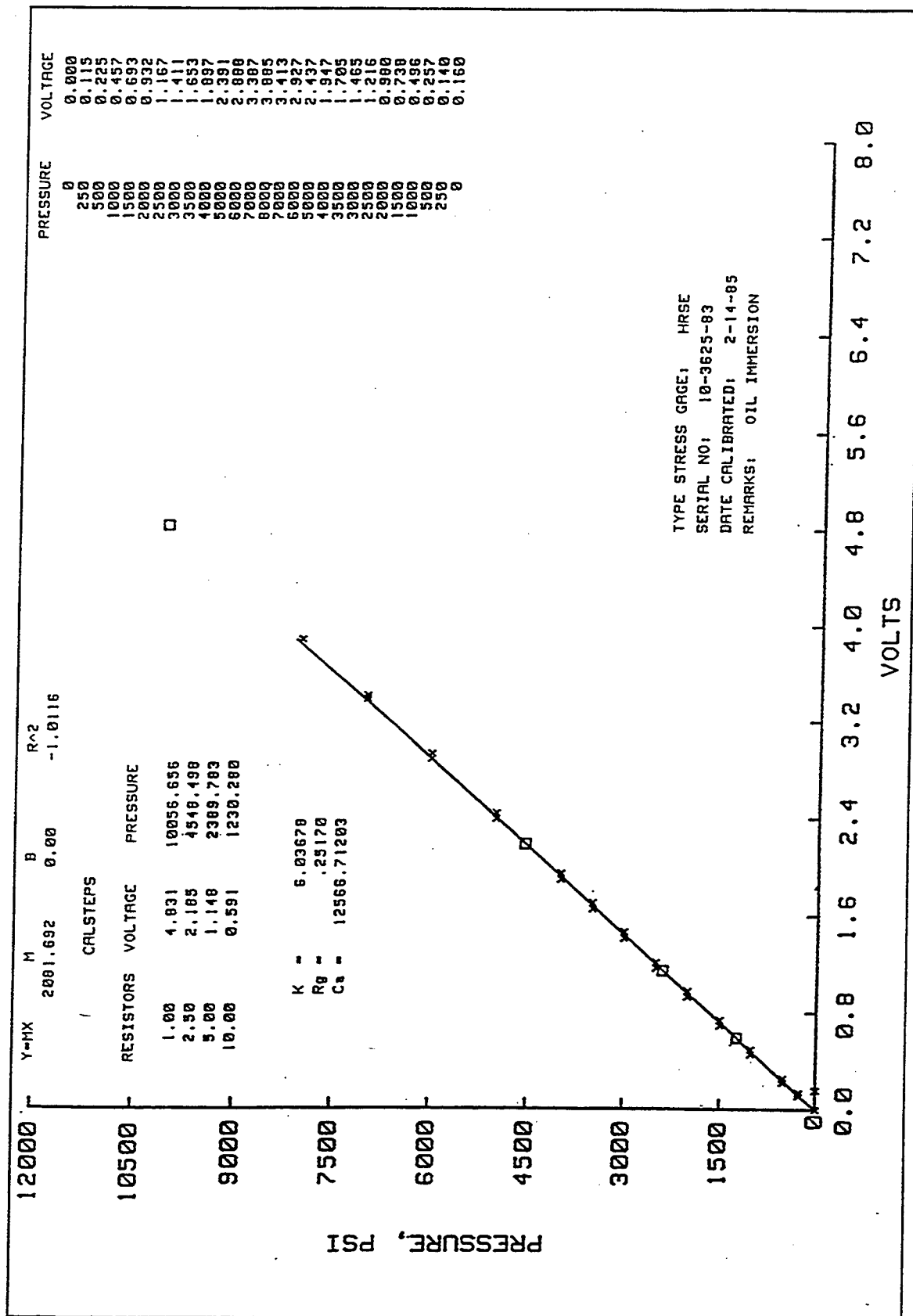
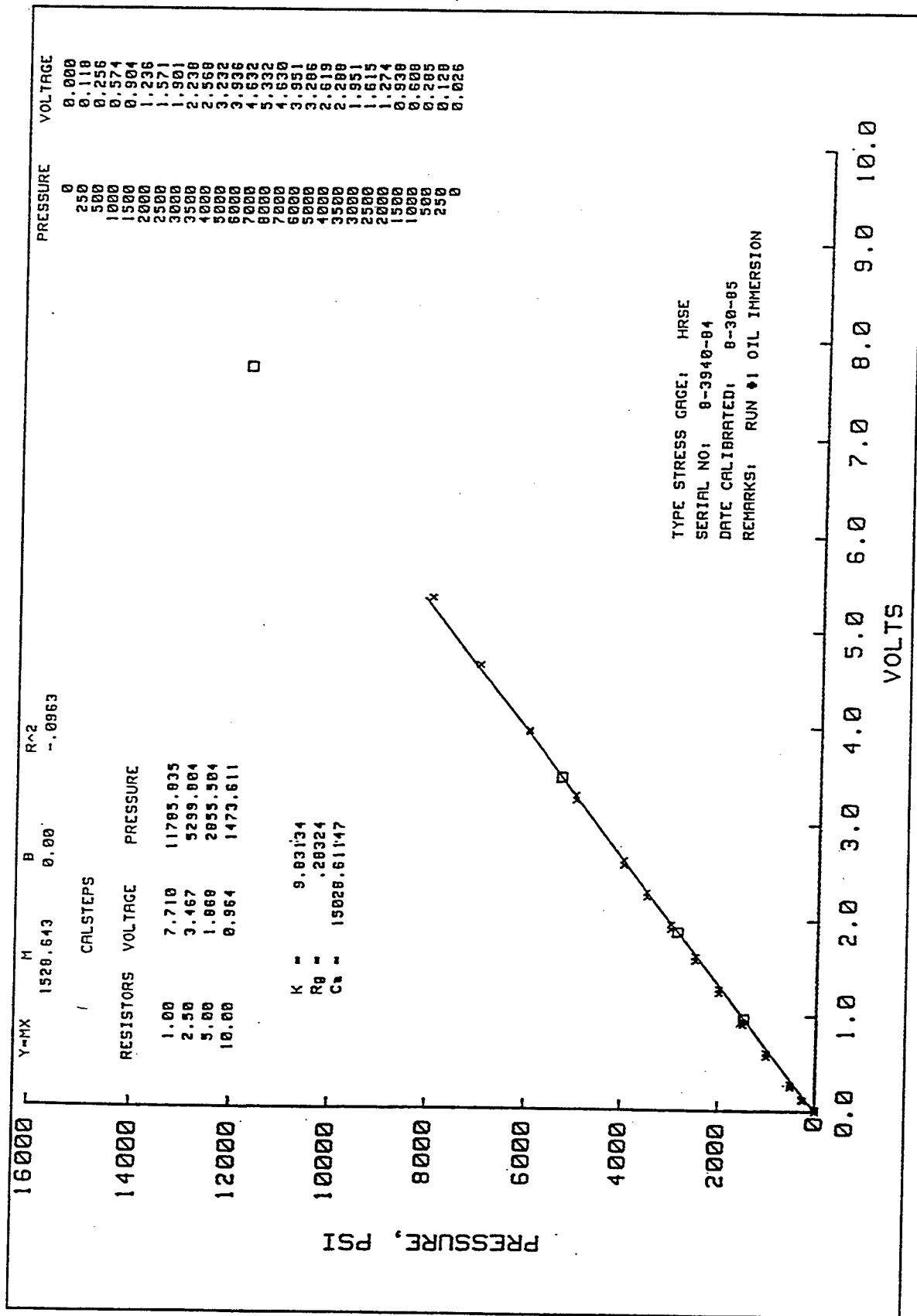
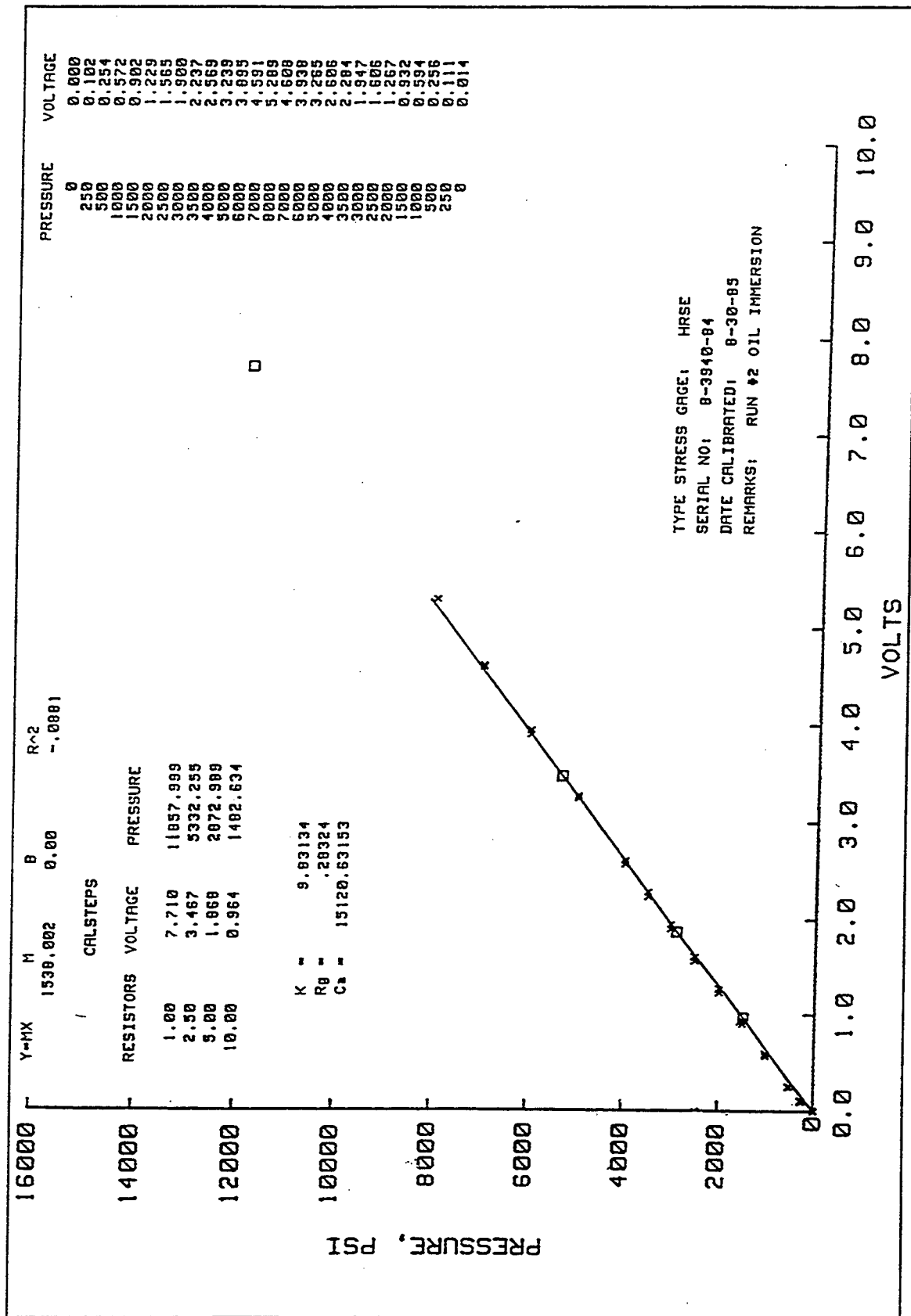
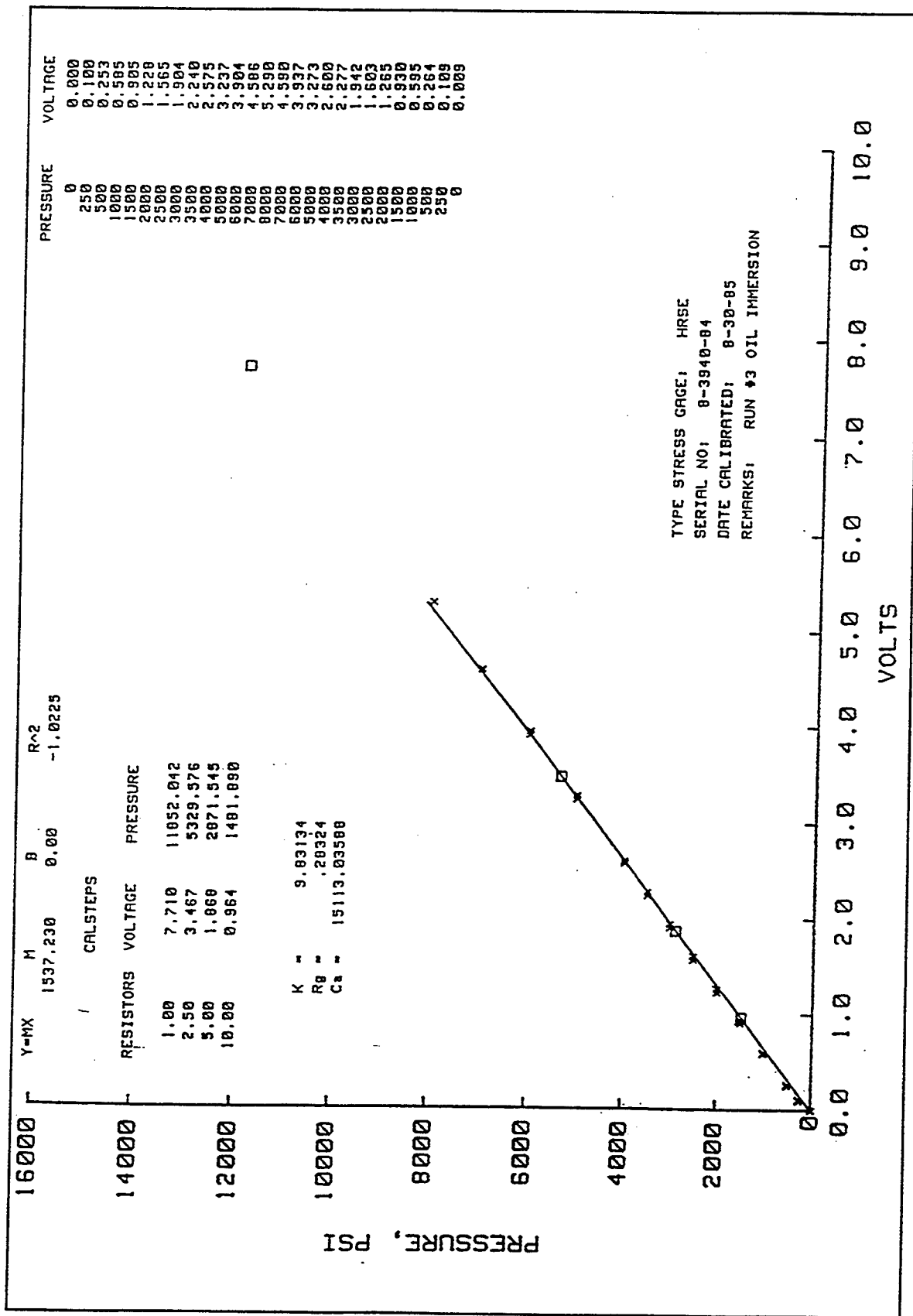


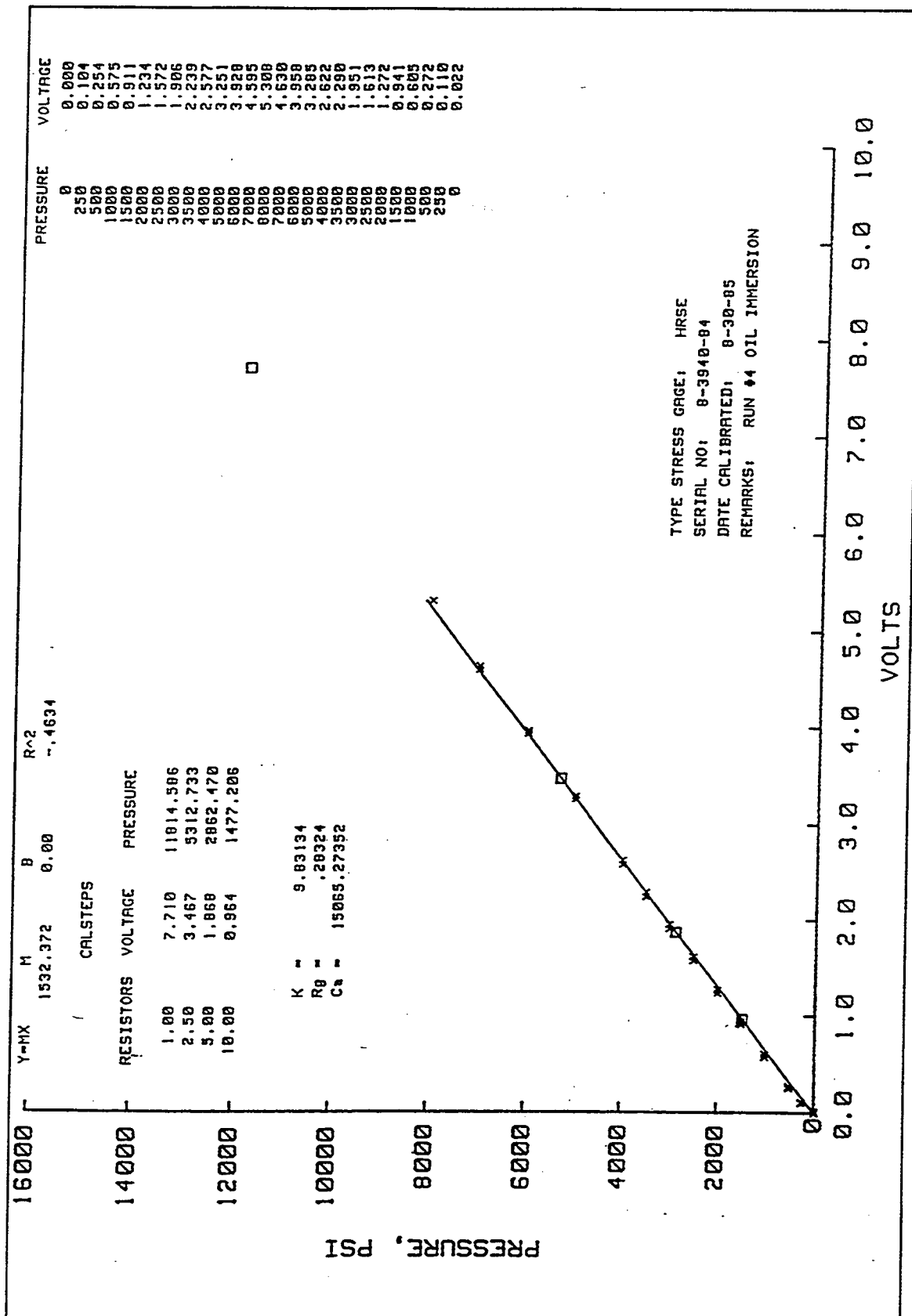
Plate 24

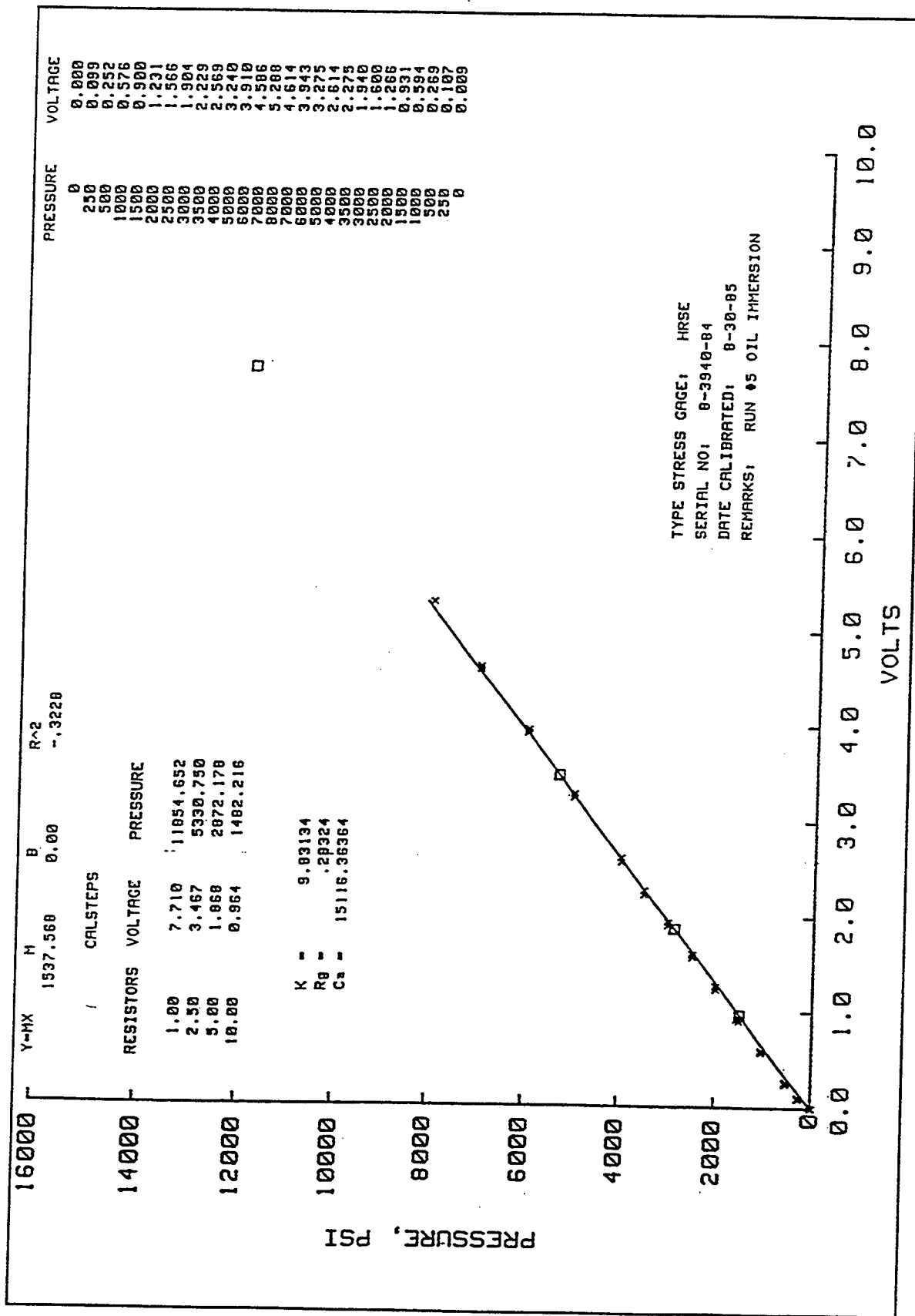


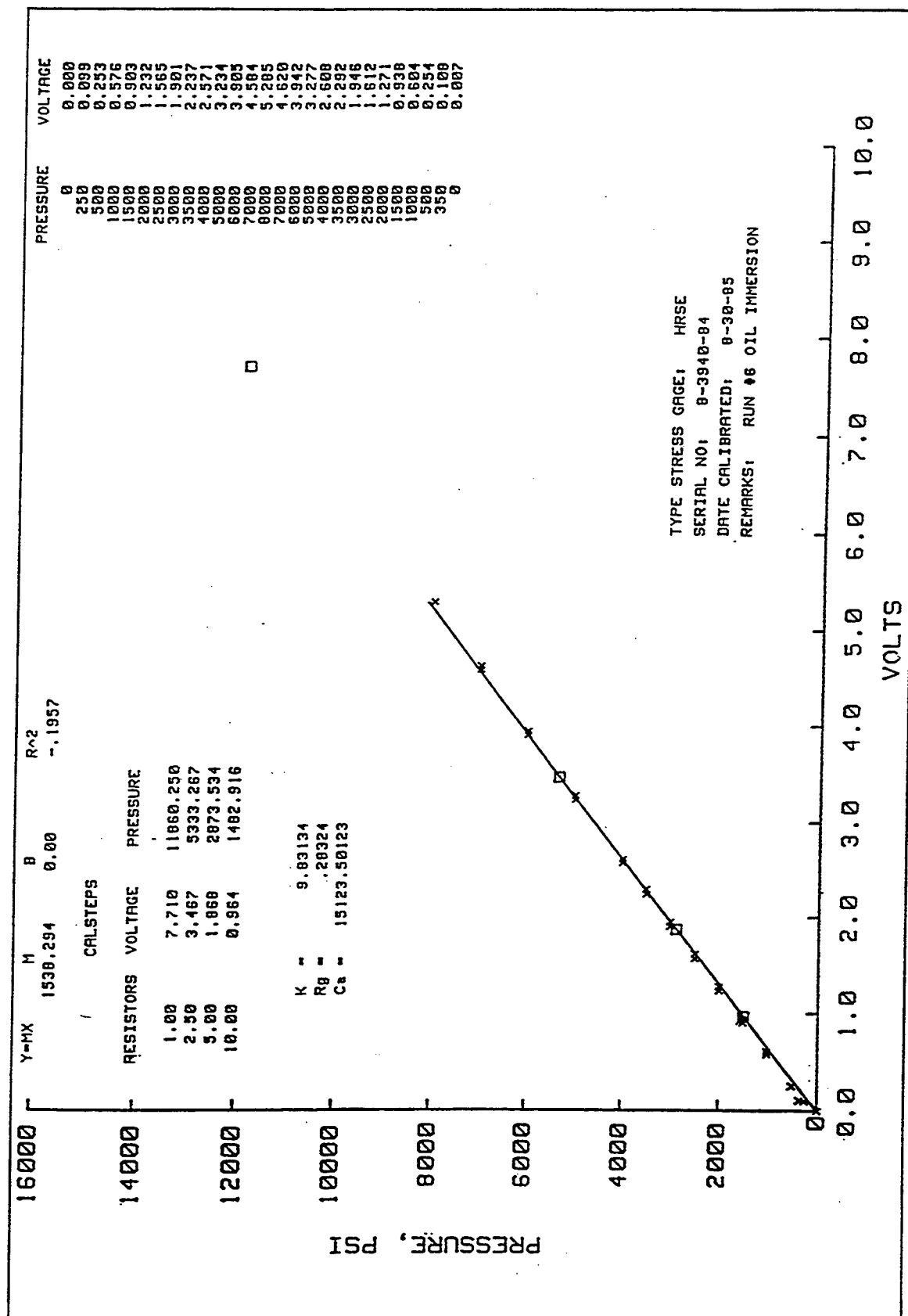




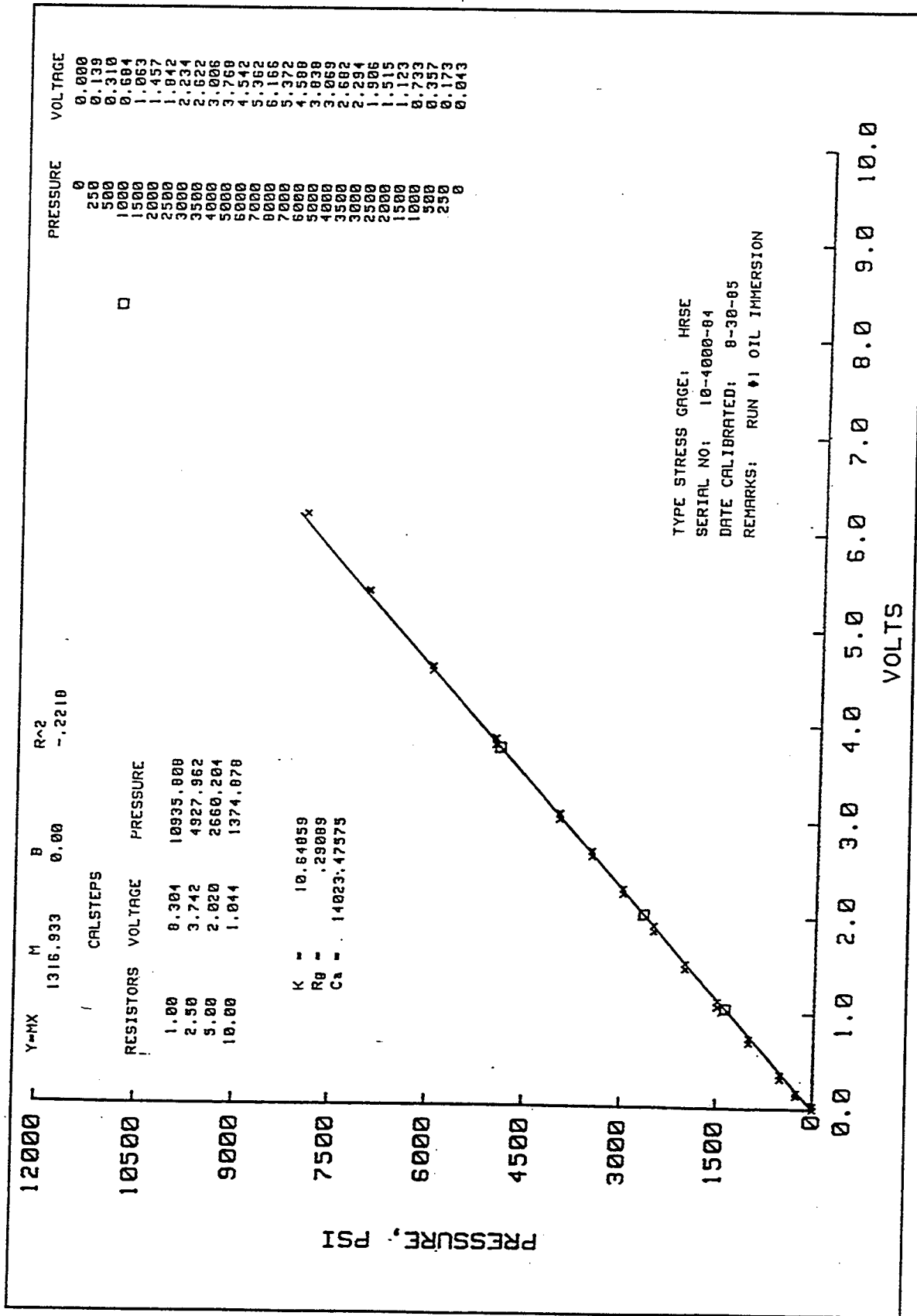


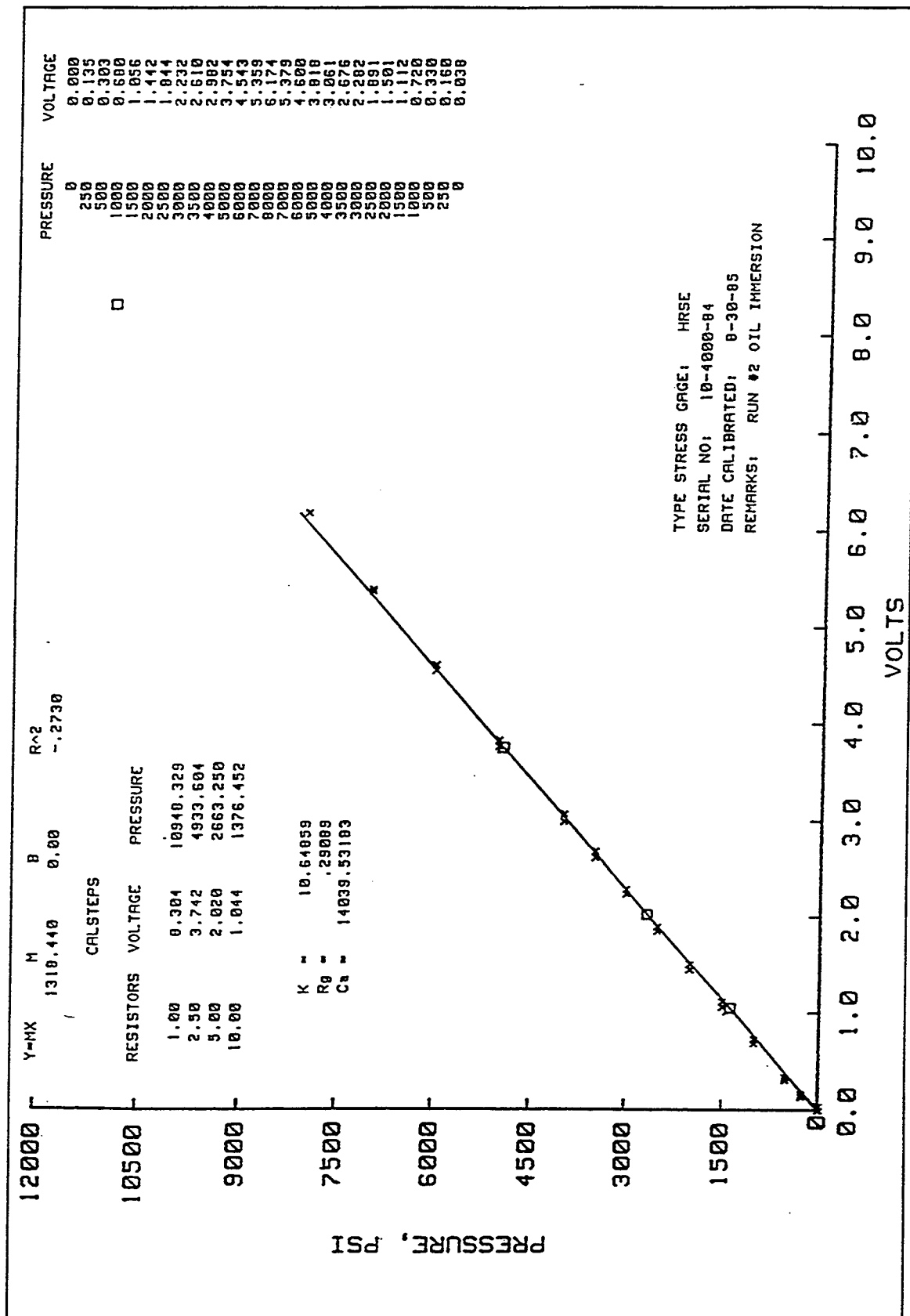


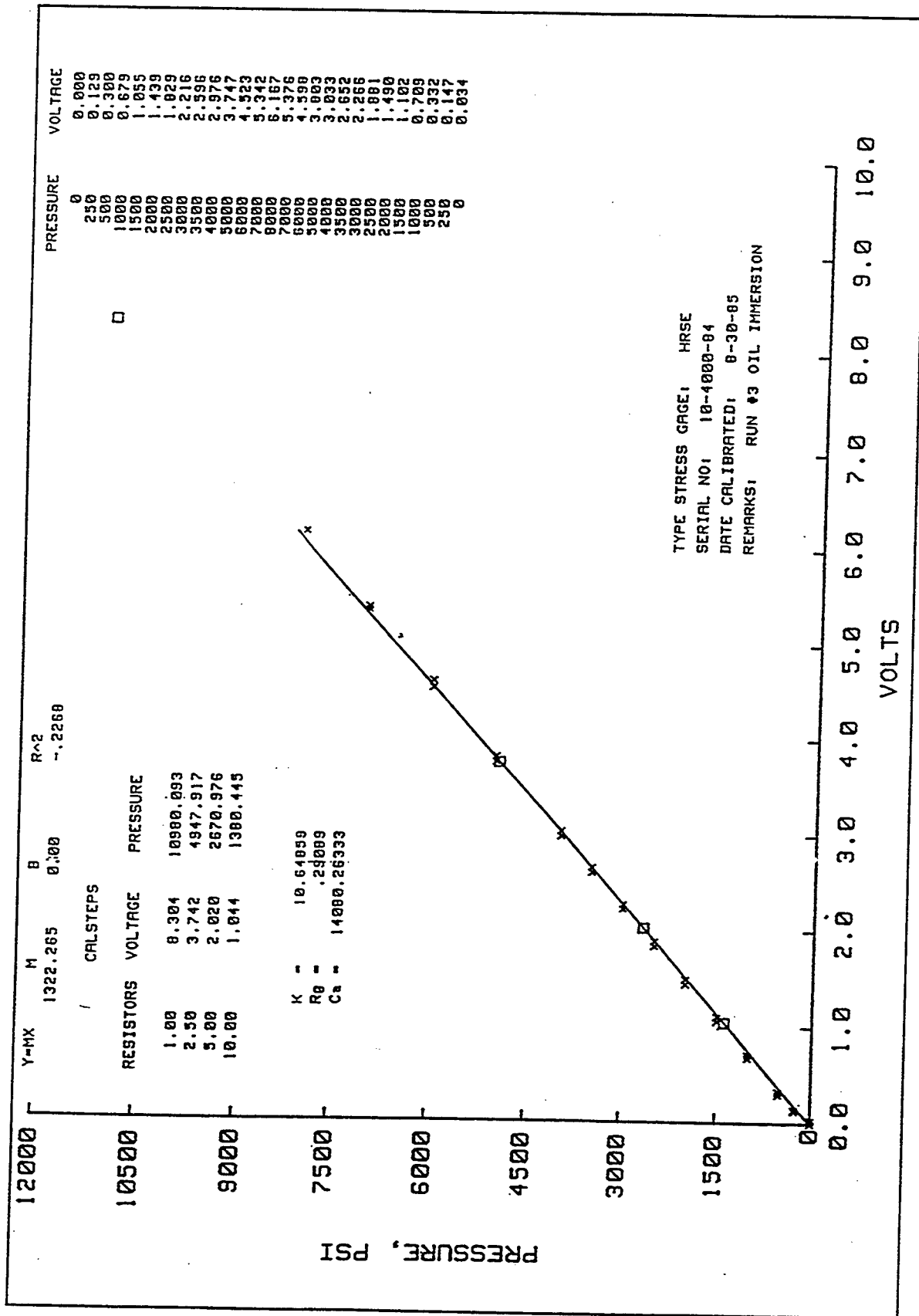


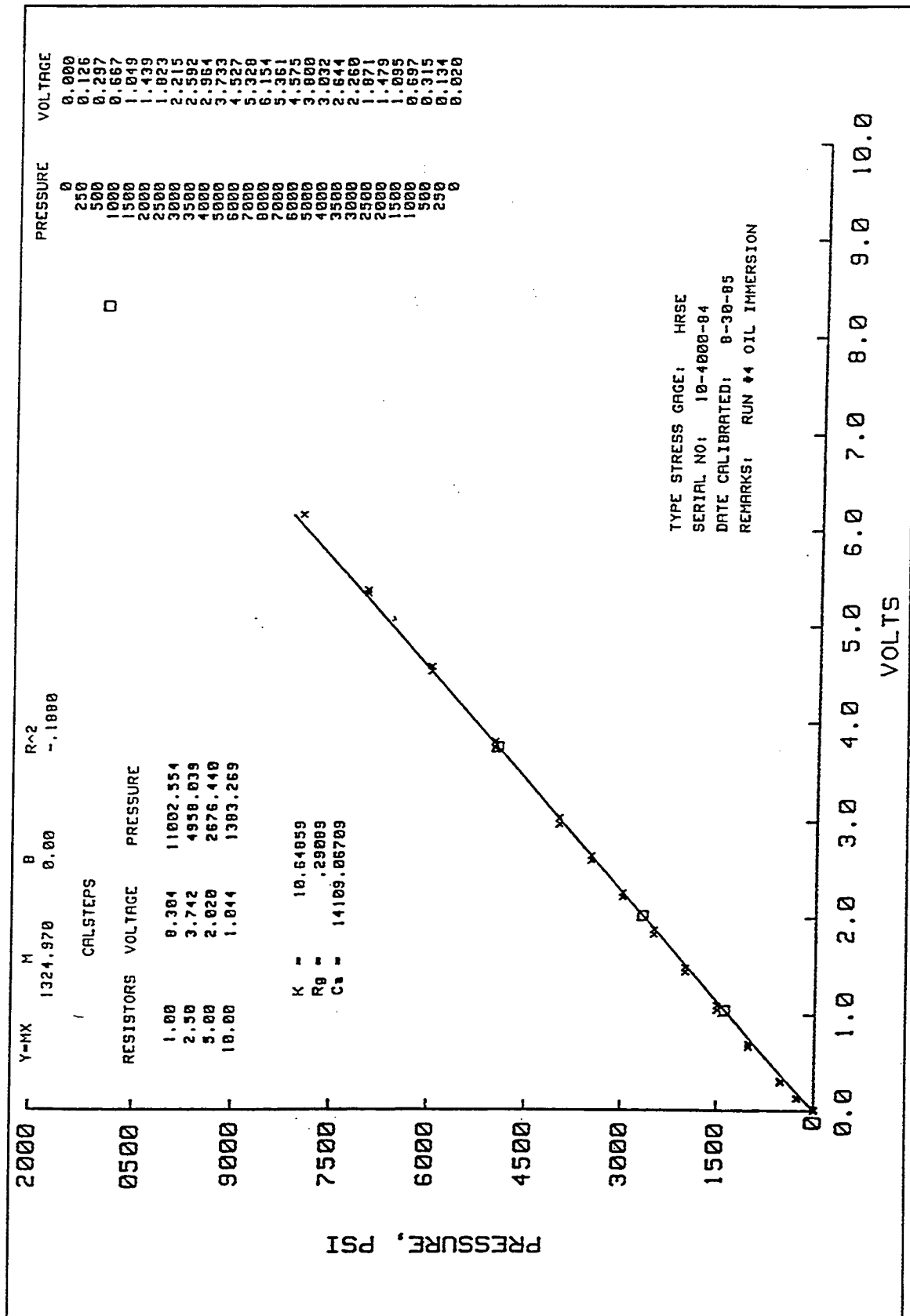


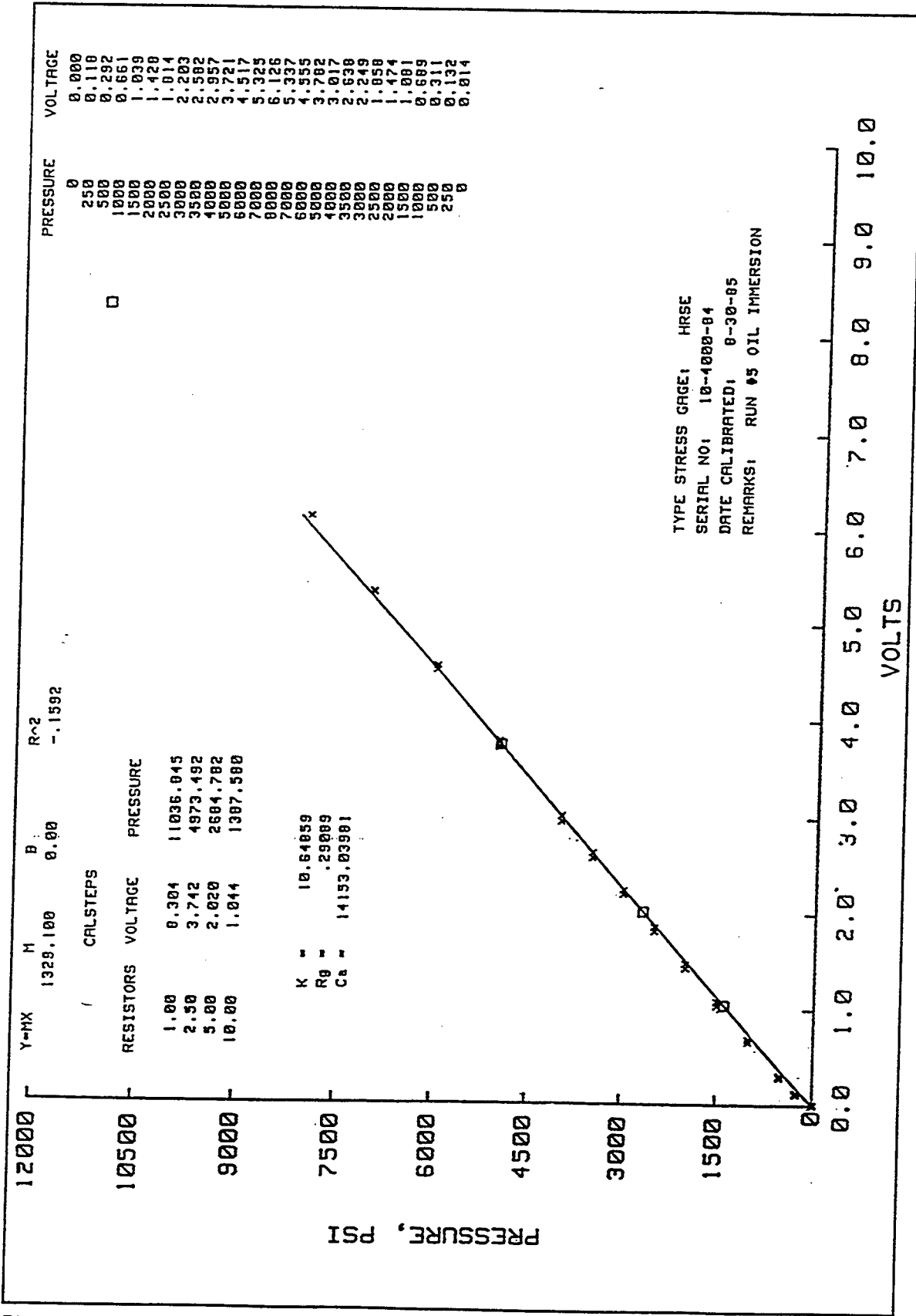


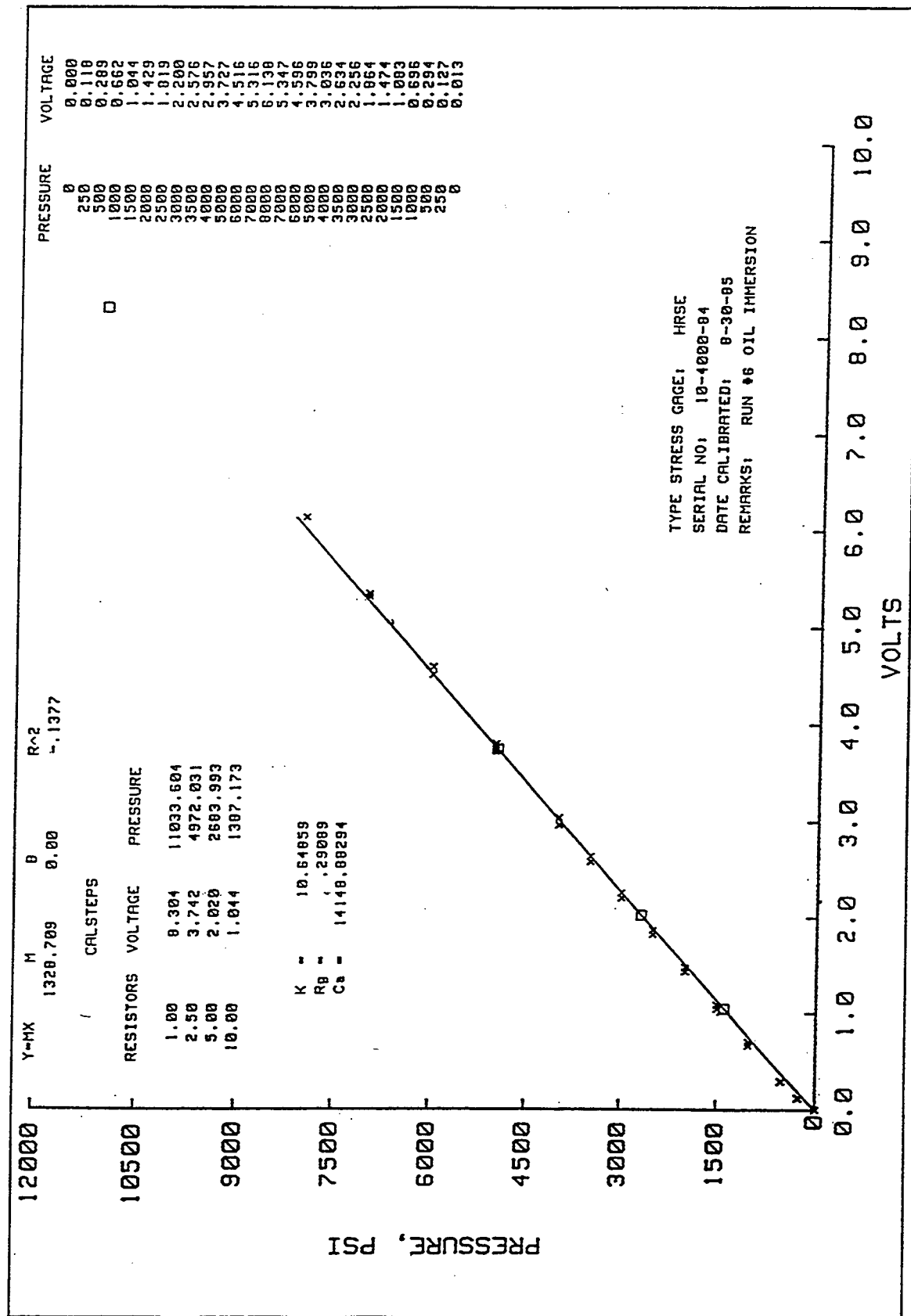


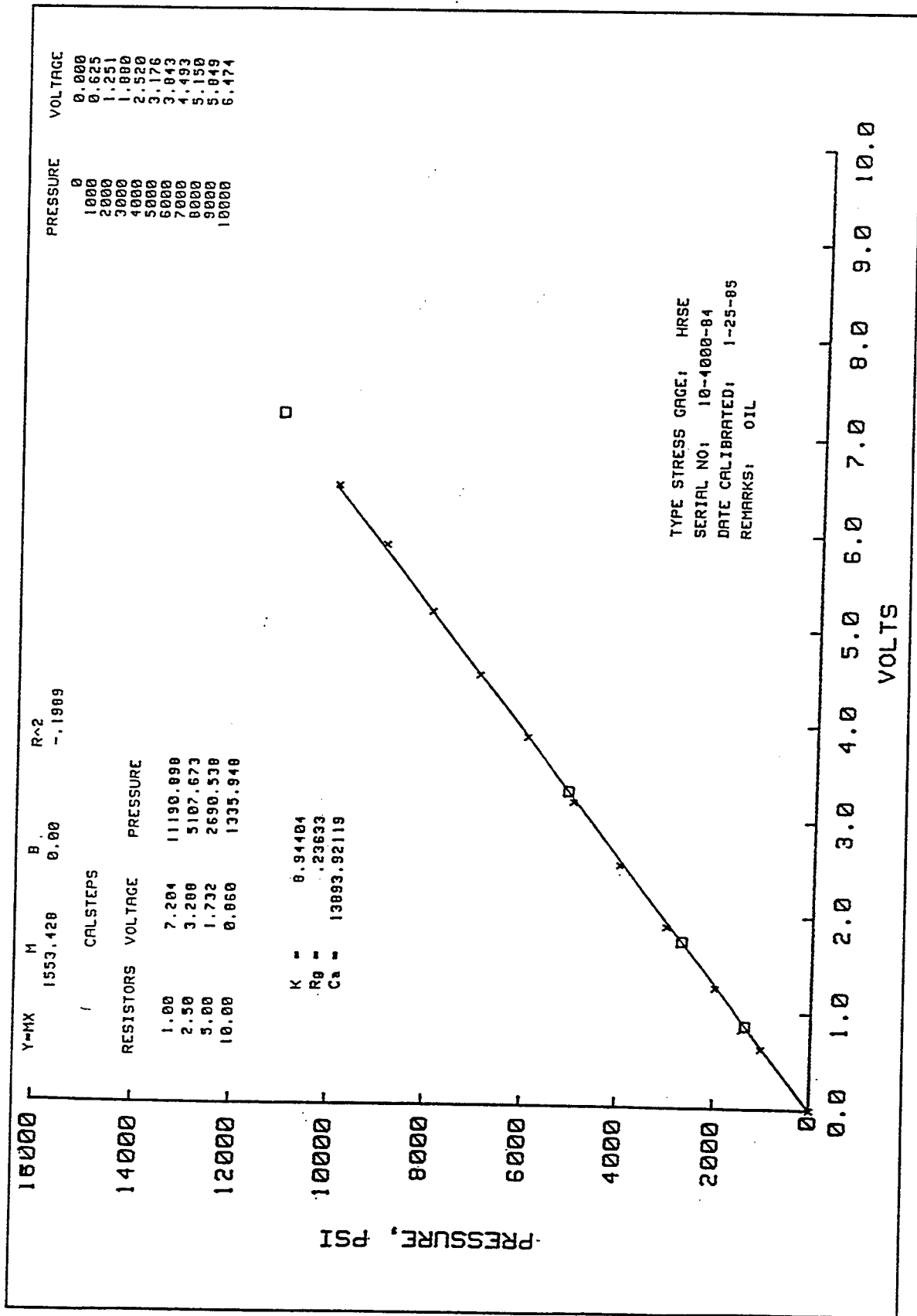


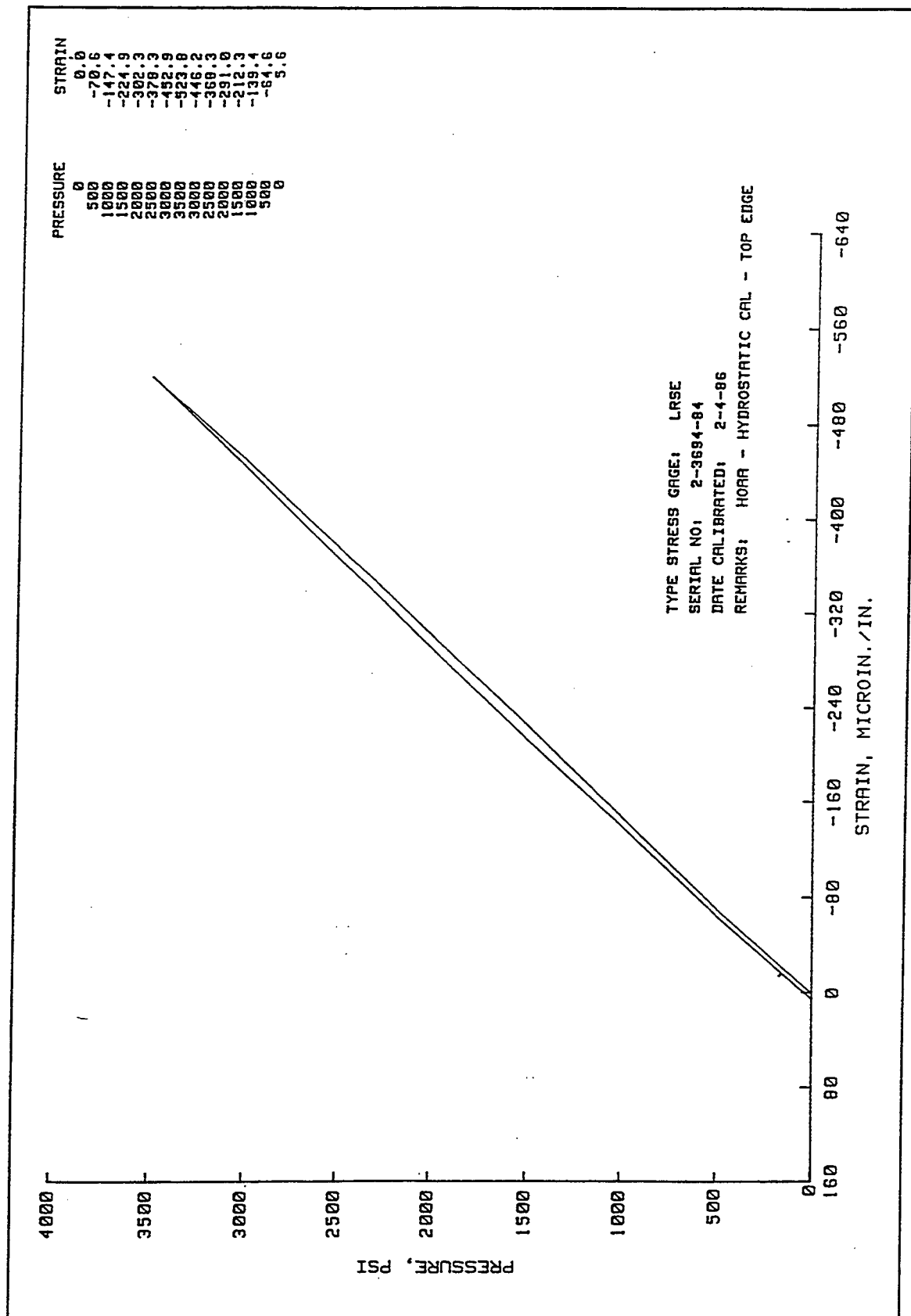




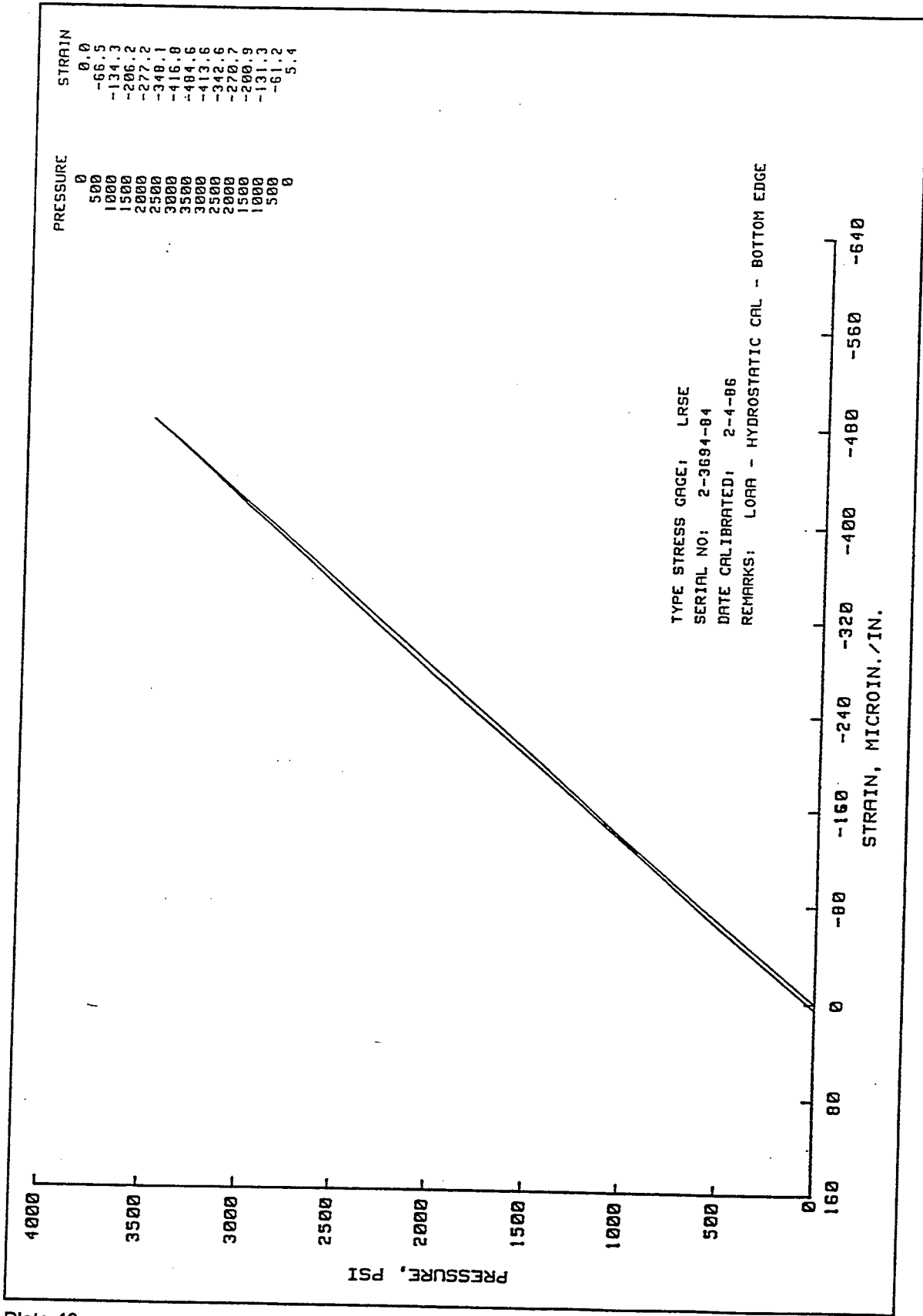


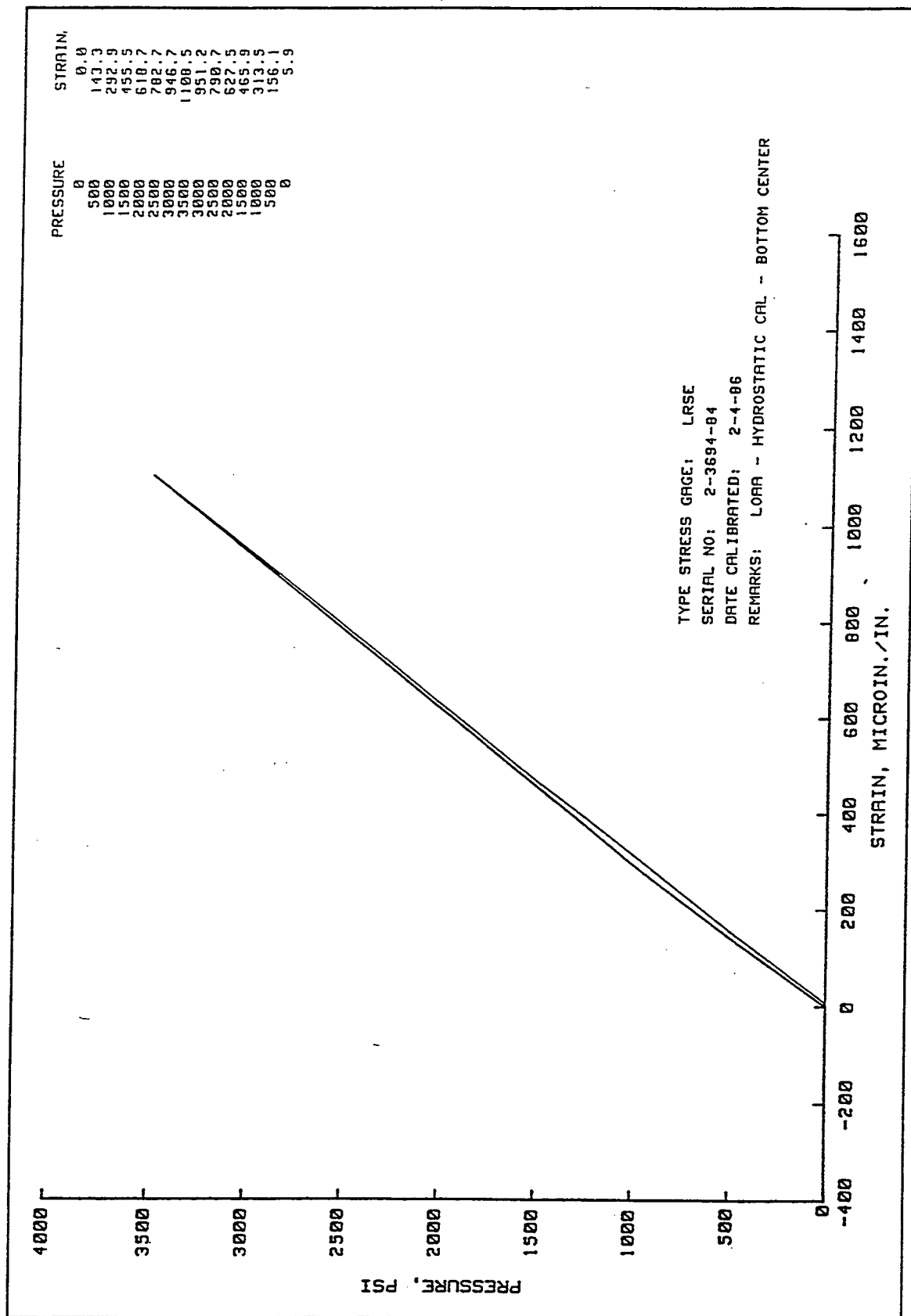












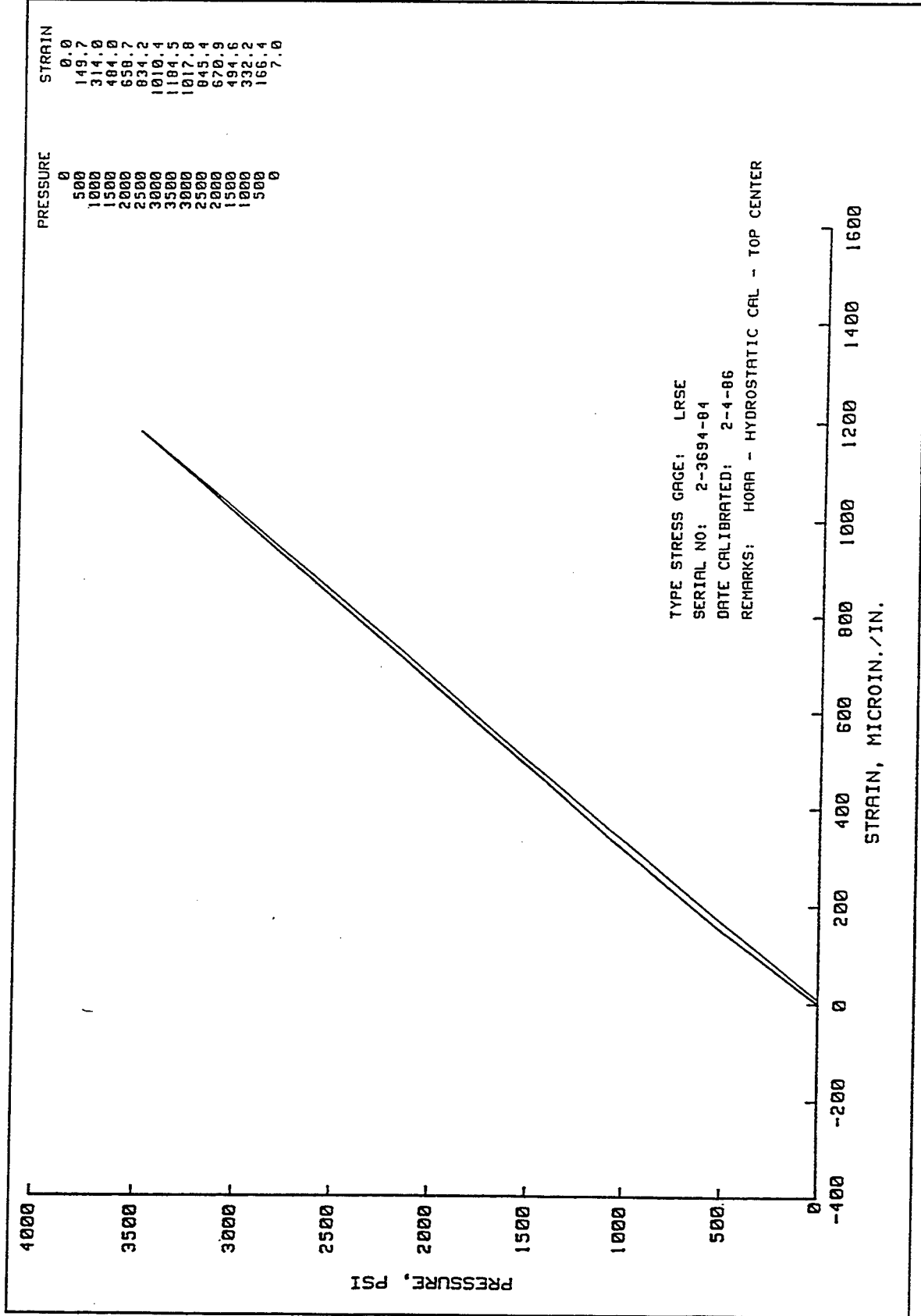
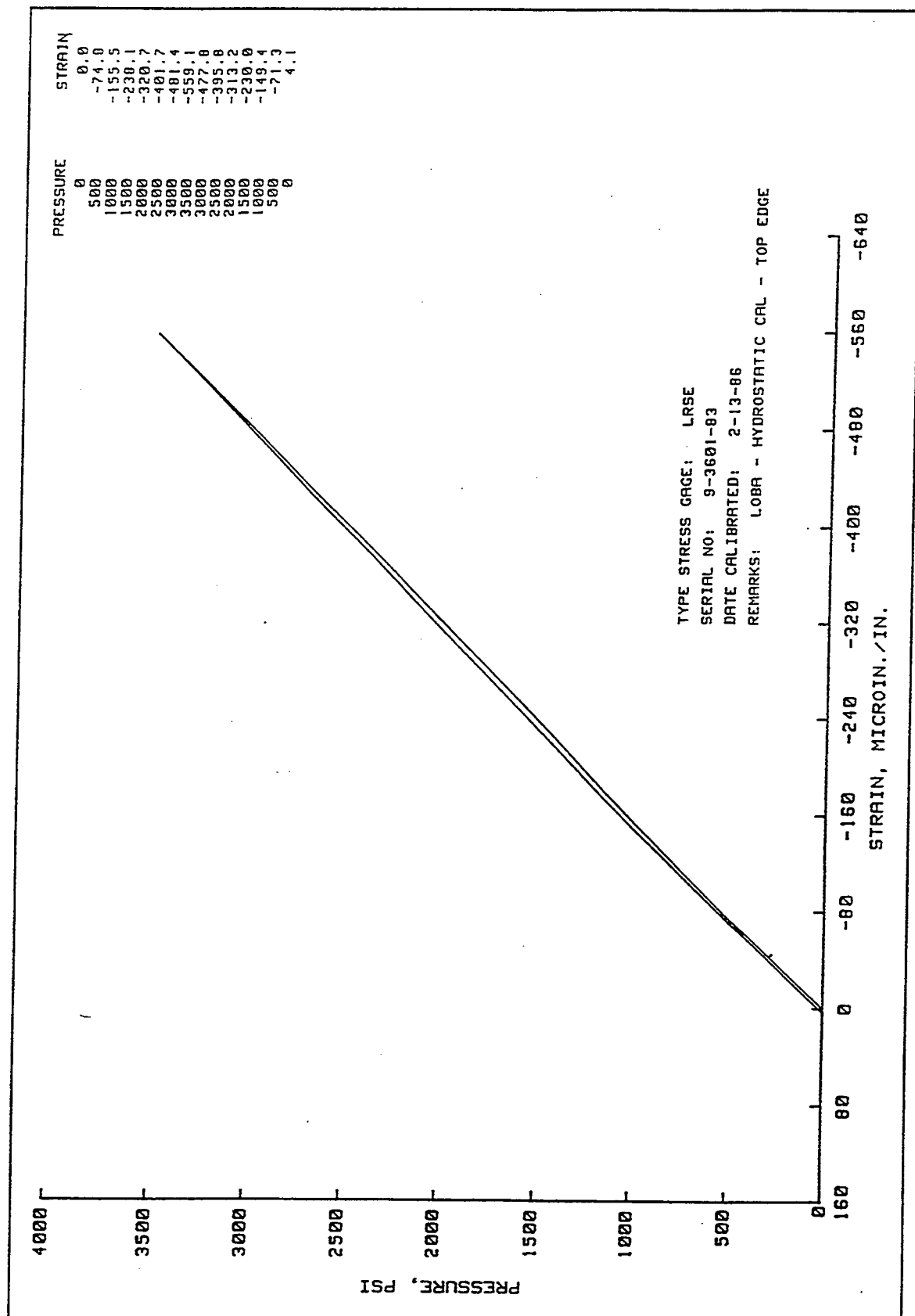


Plate 42



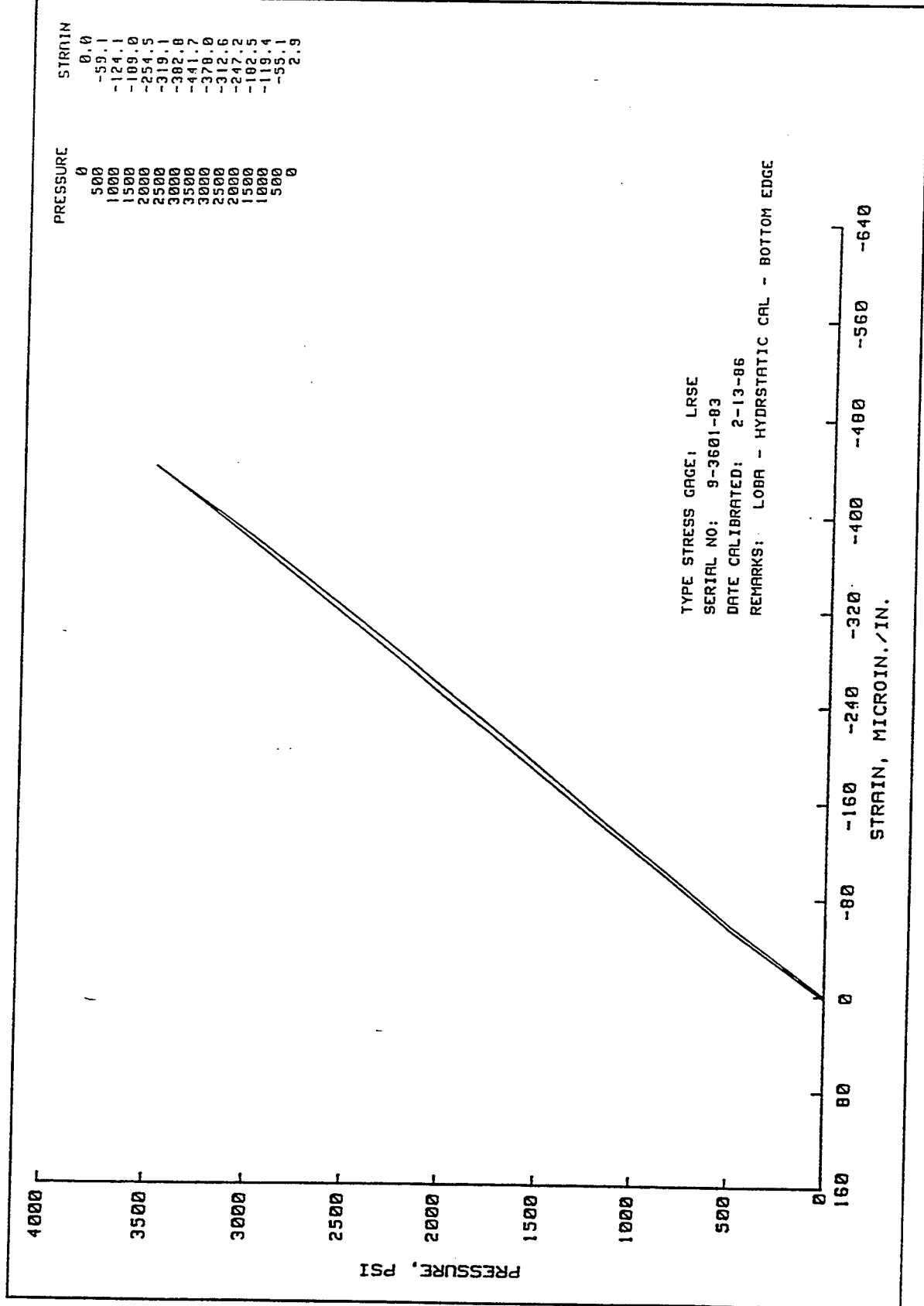


Plate 44

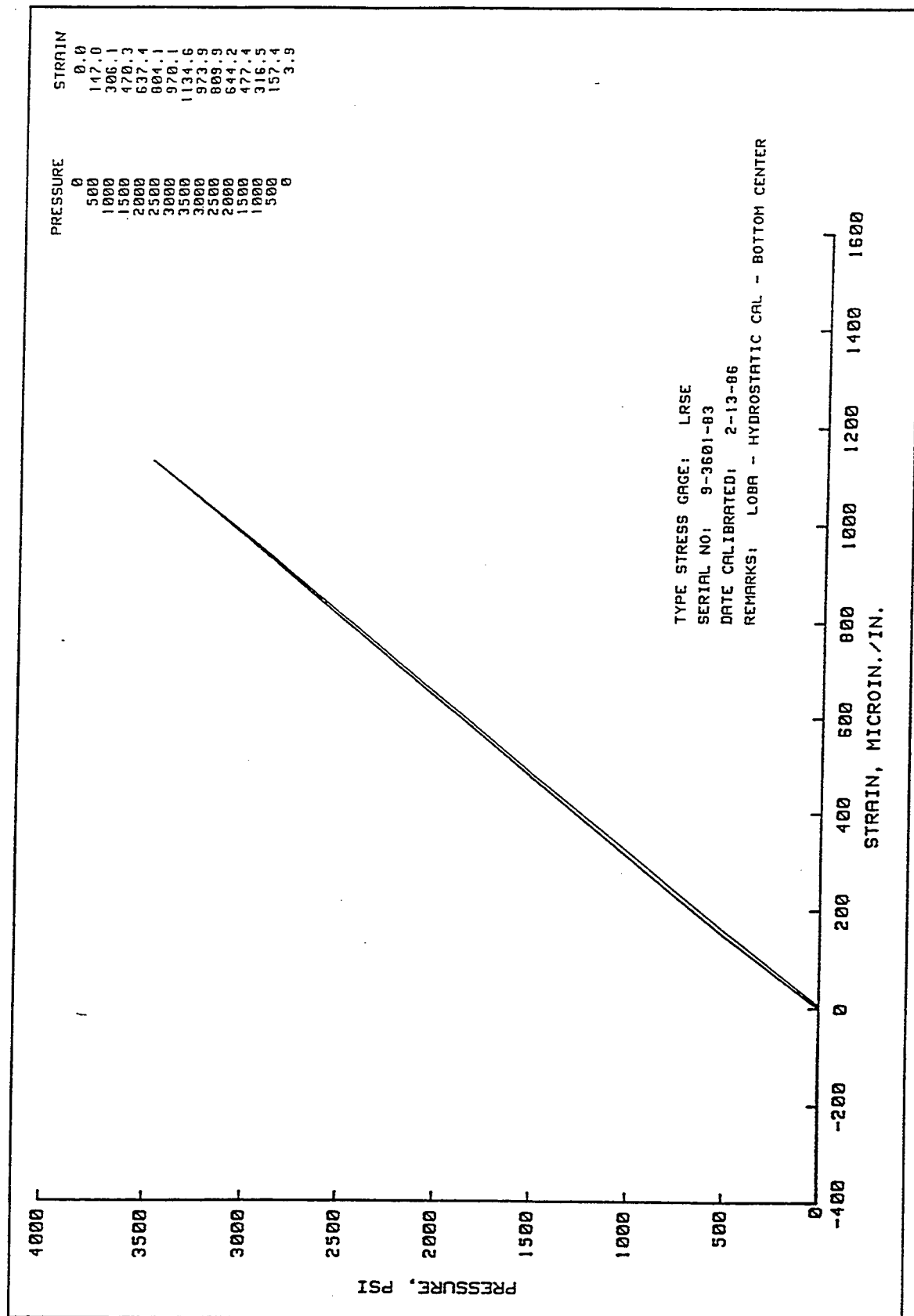
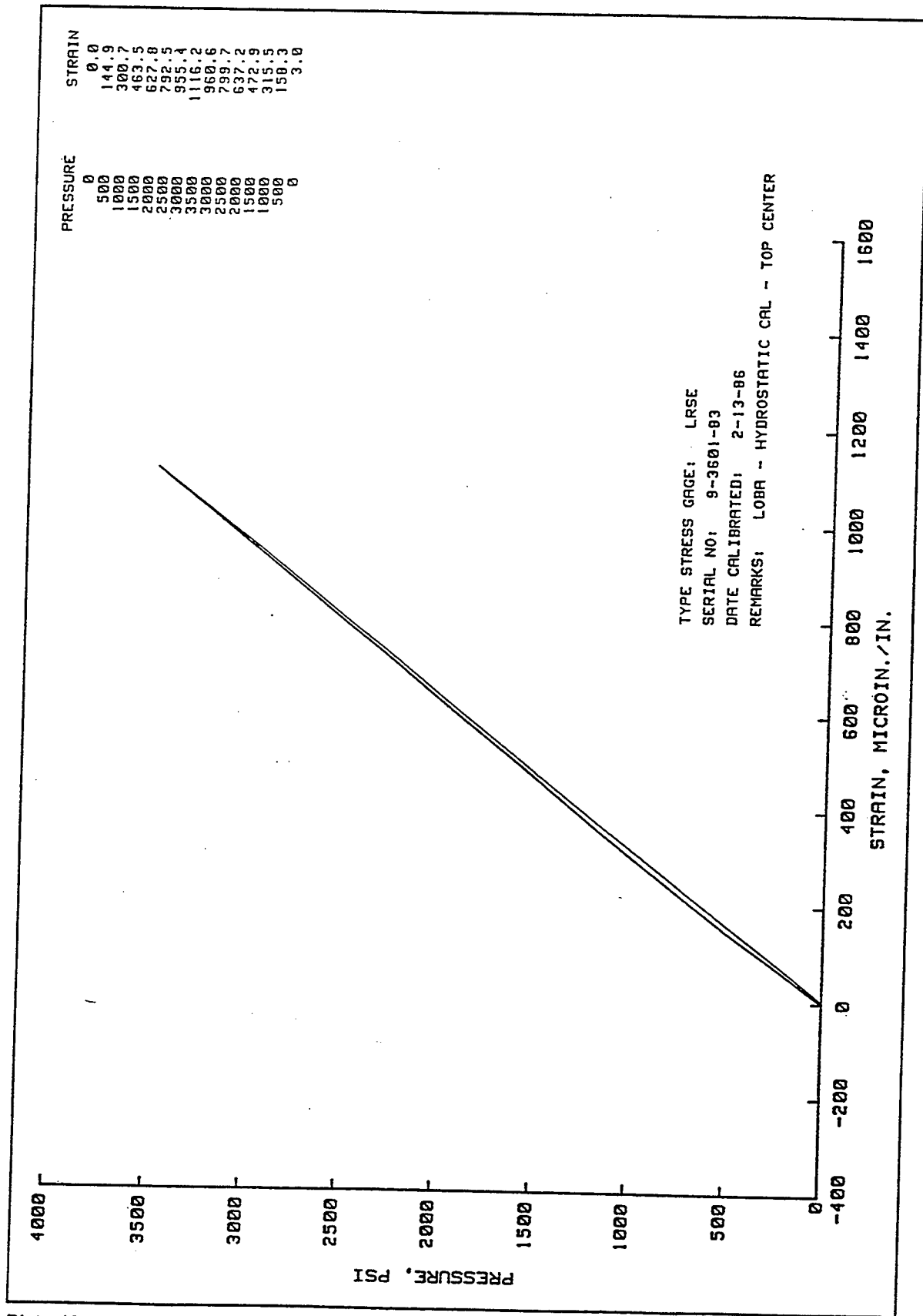
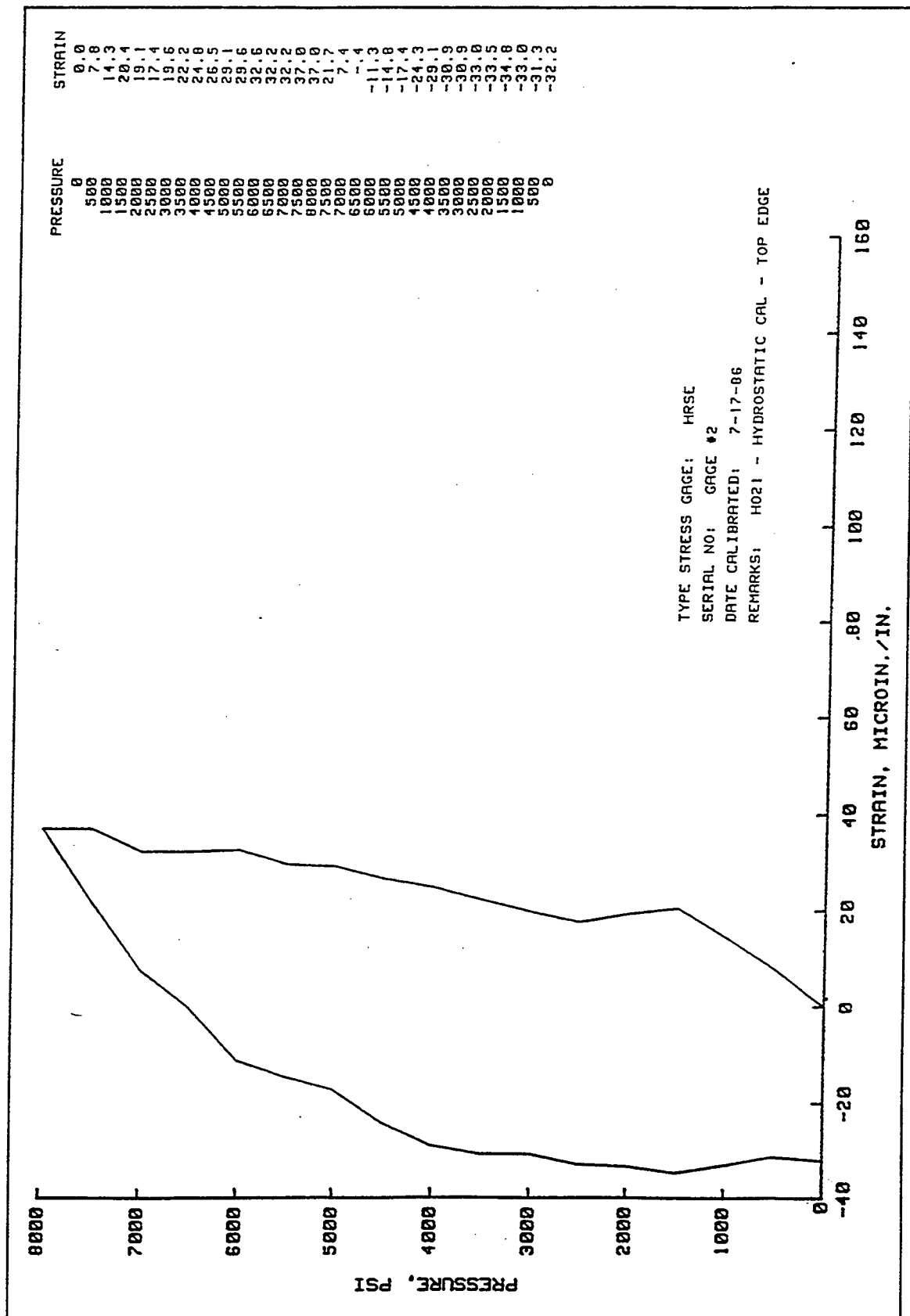


Plate 46







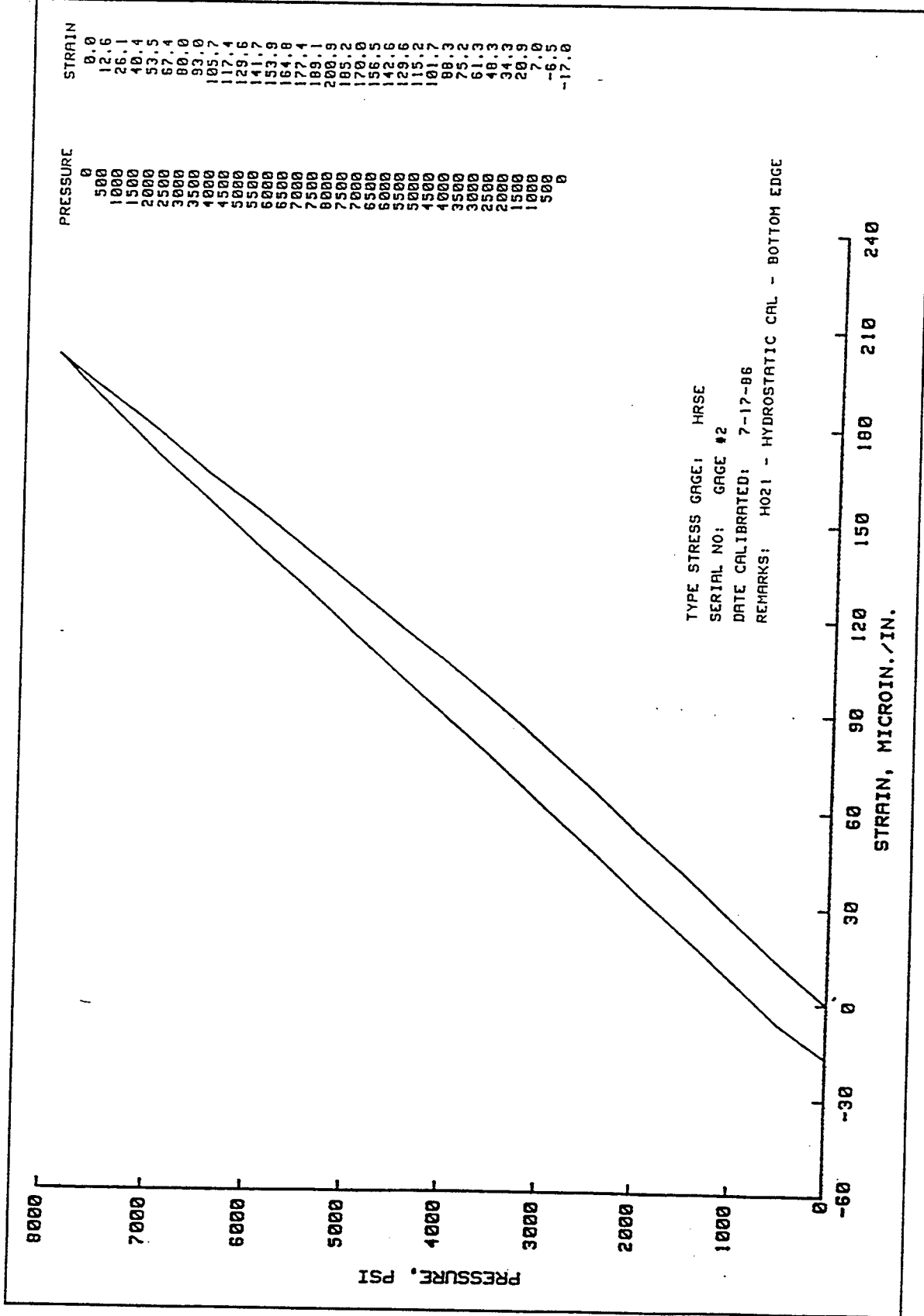
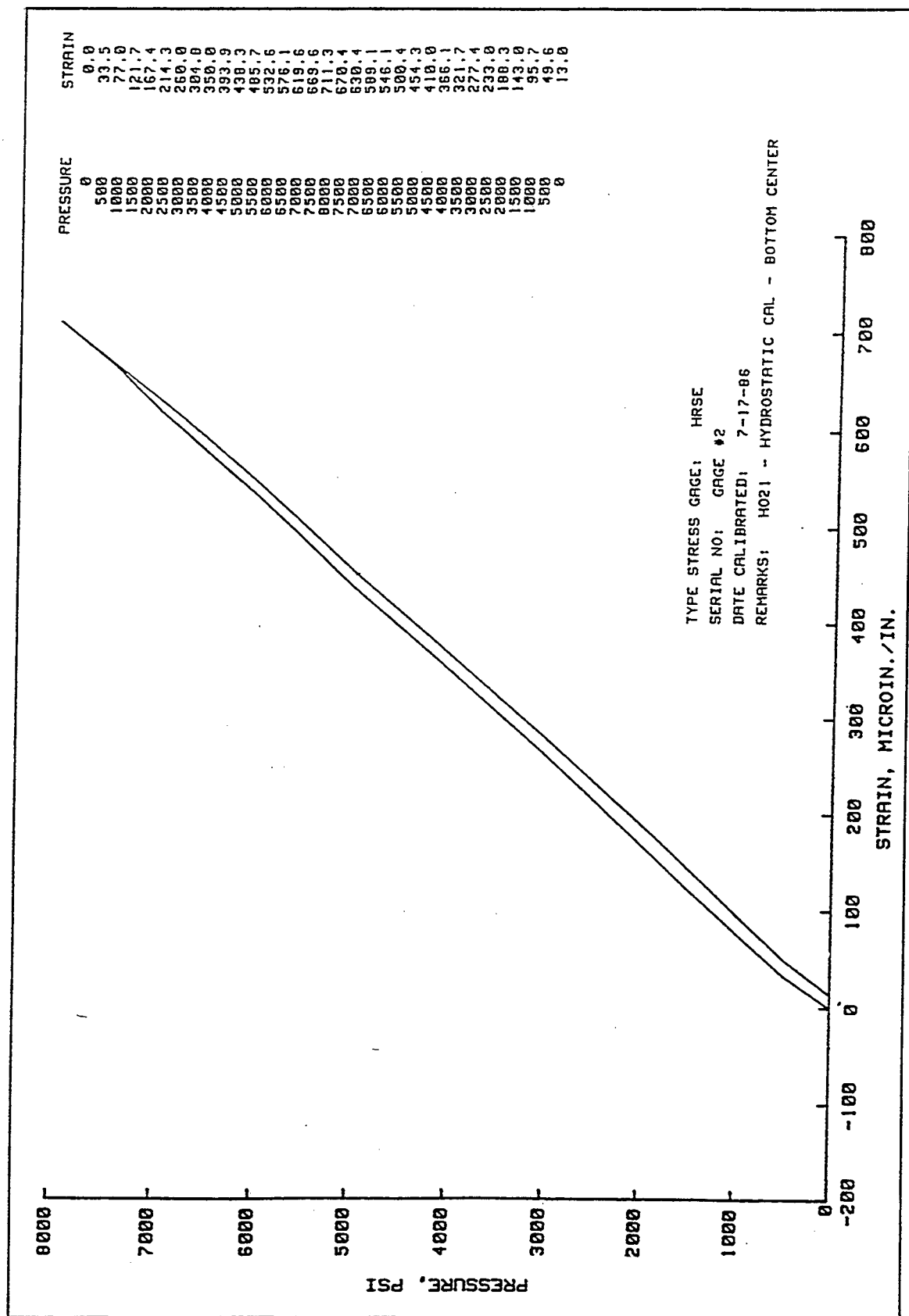
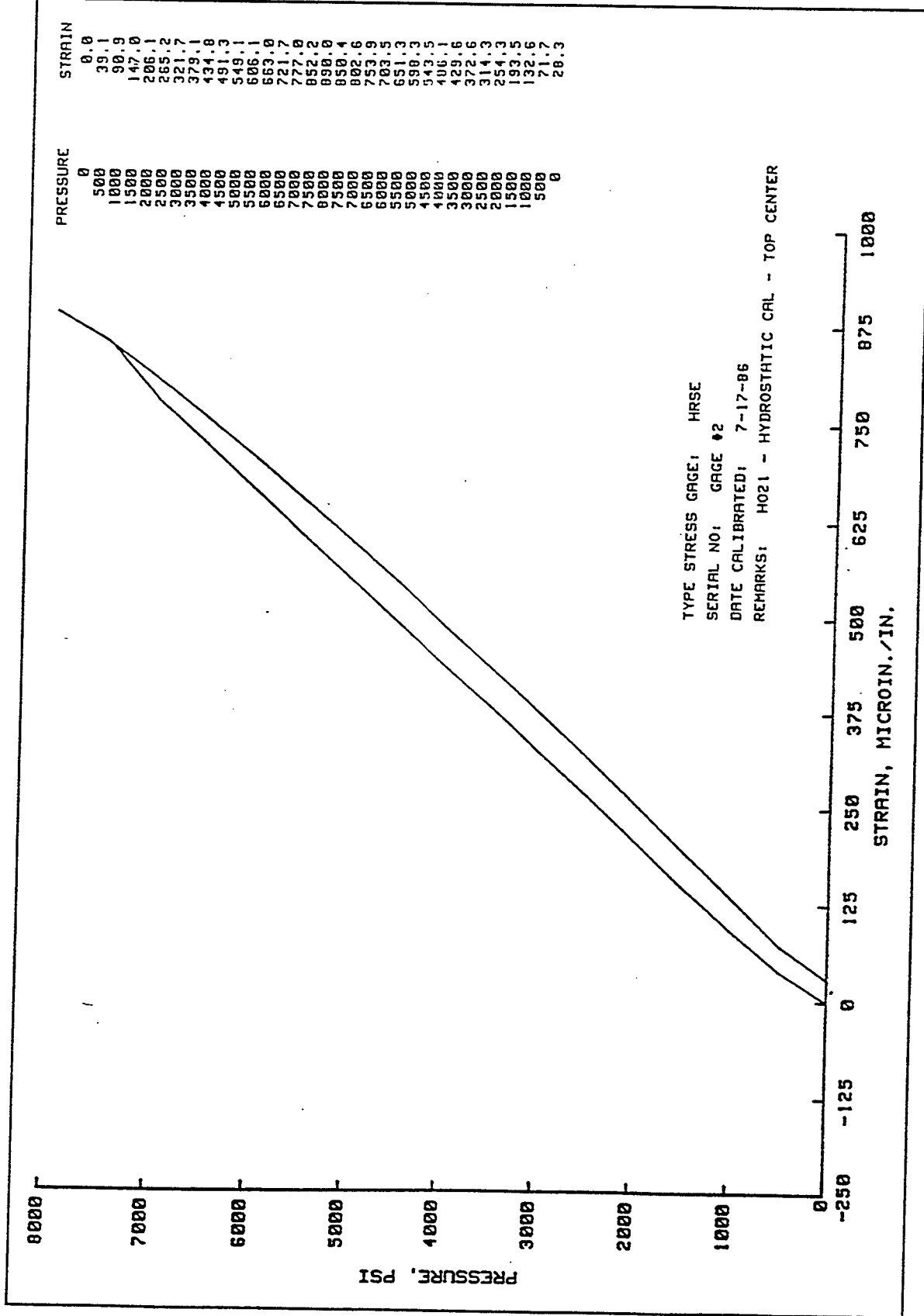
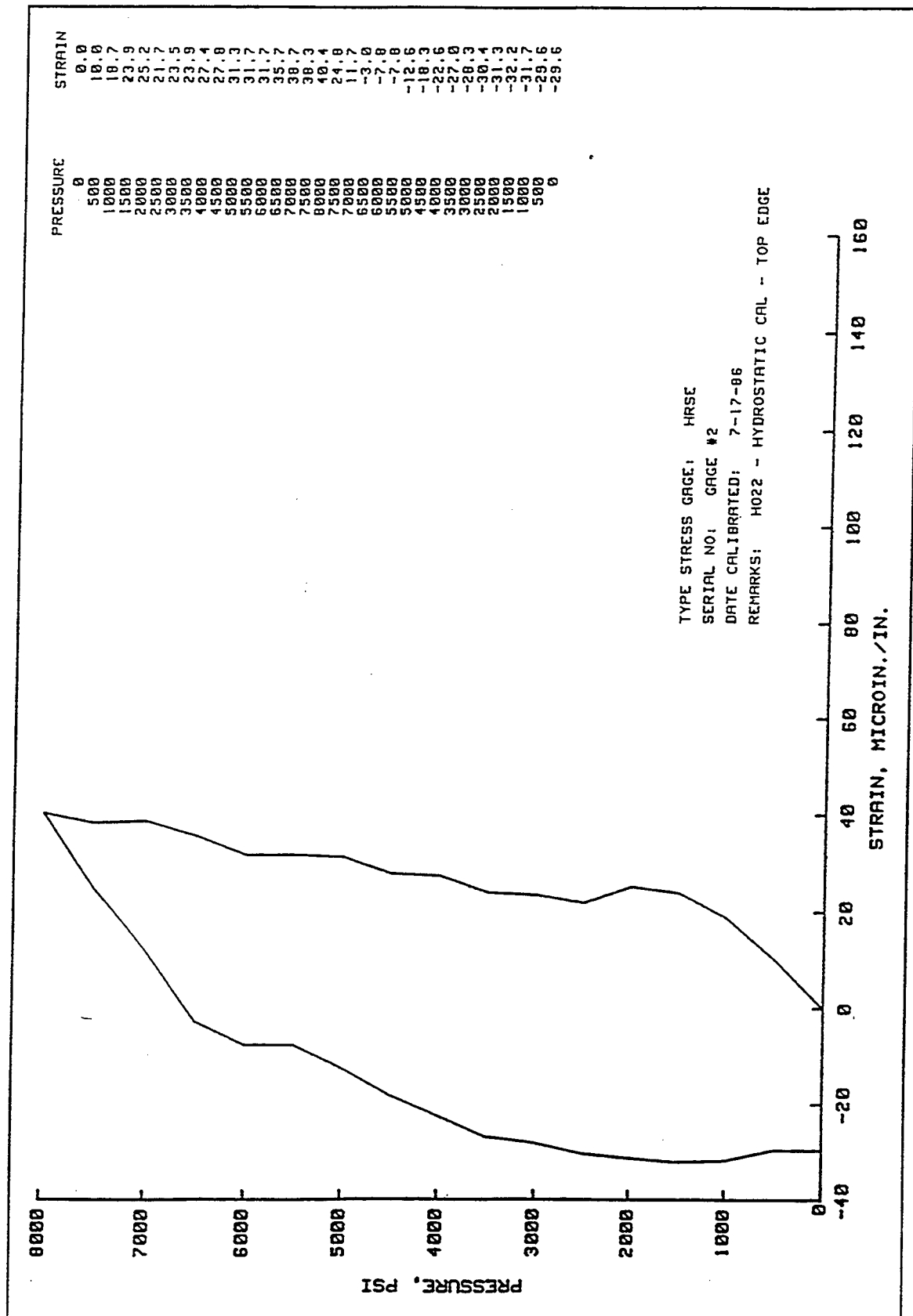
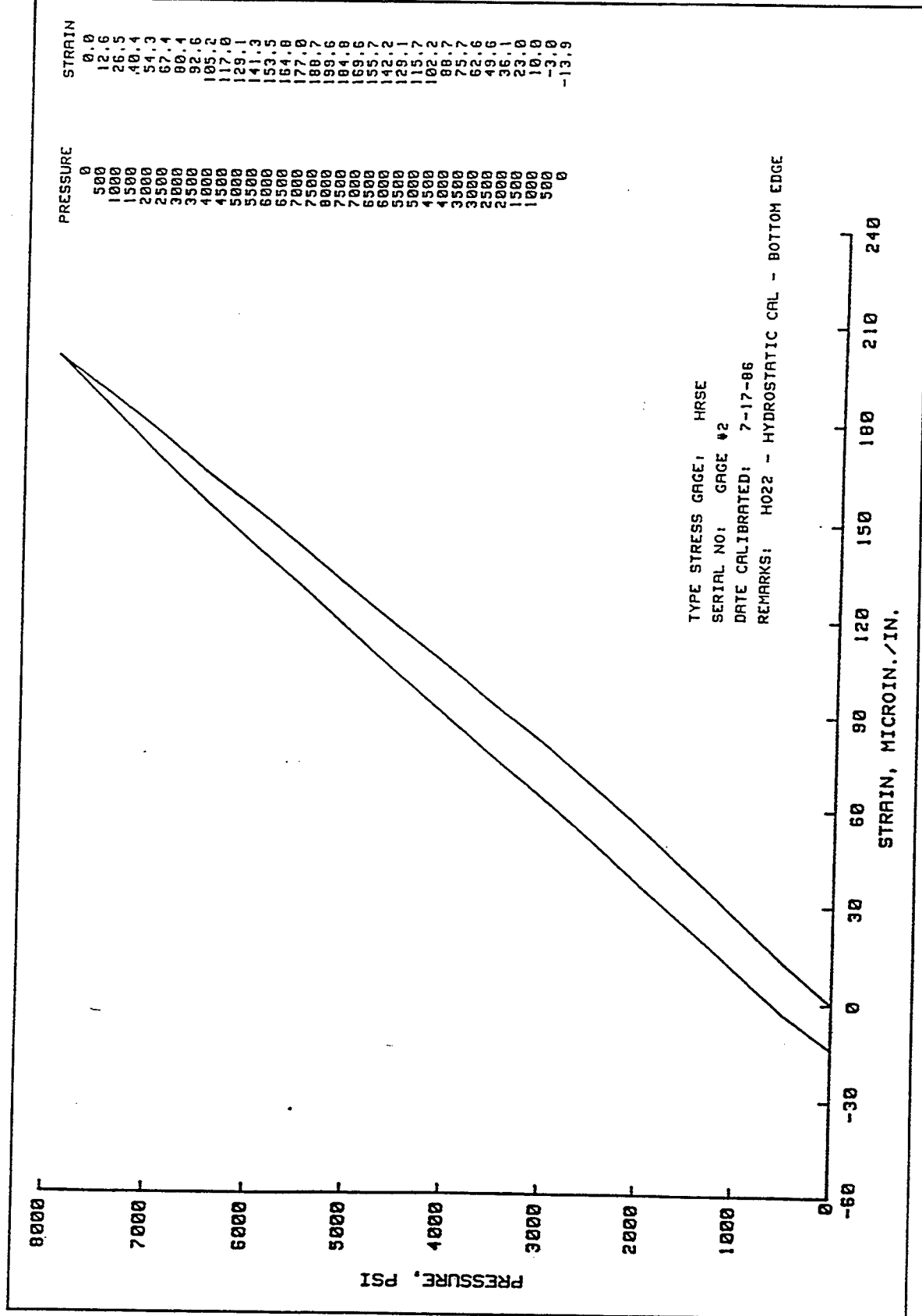


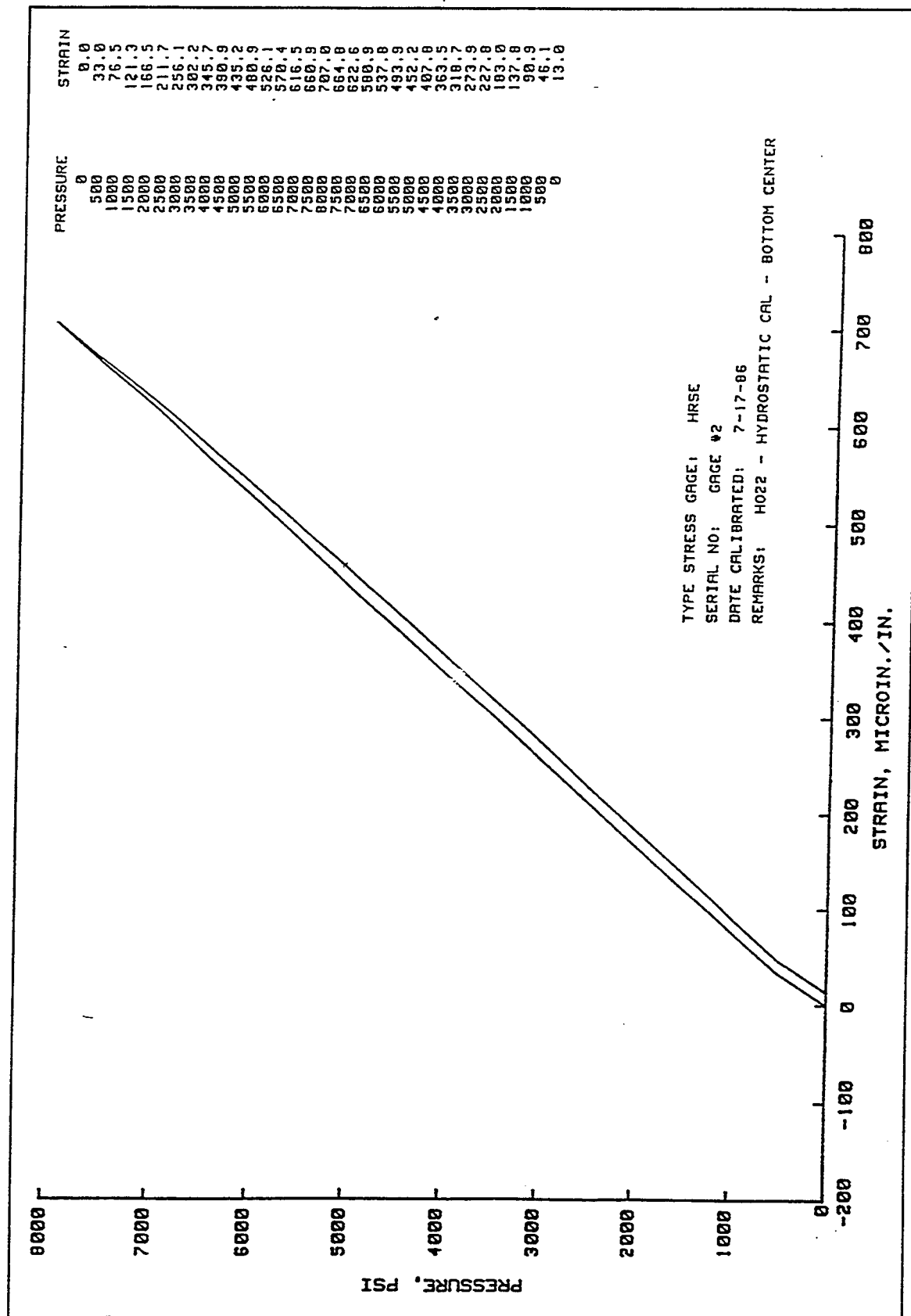
Plate 48











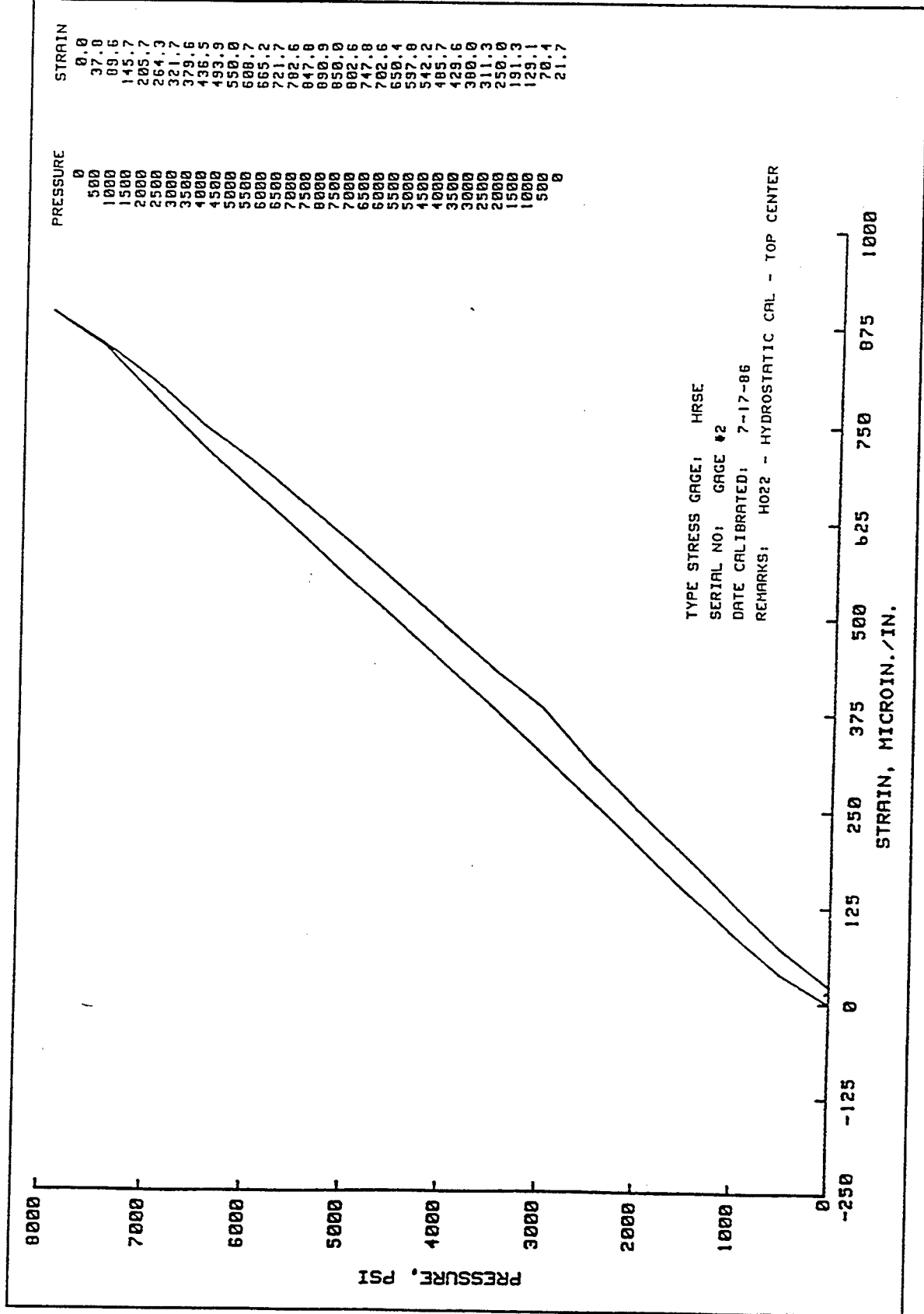
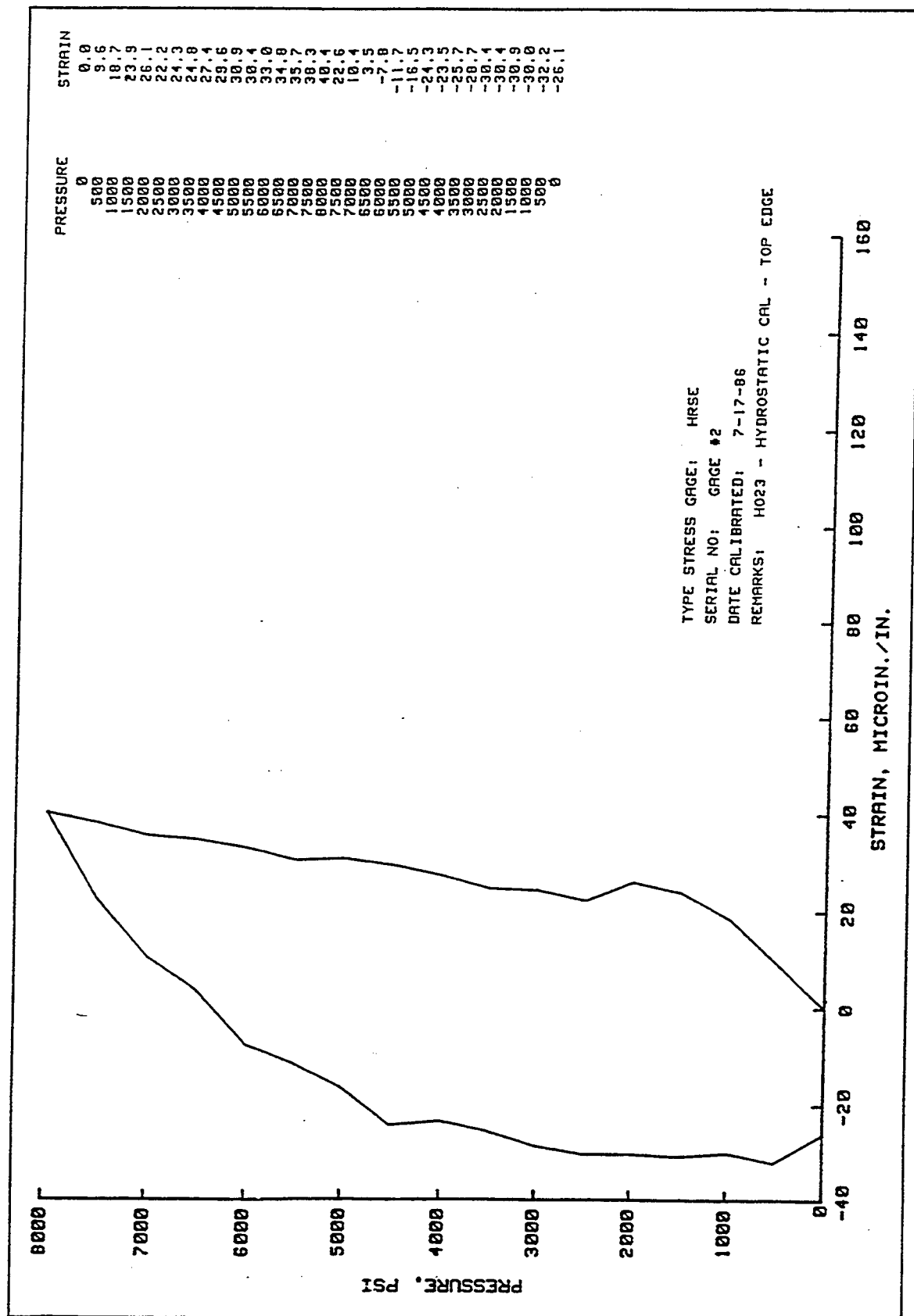


Plate 54





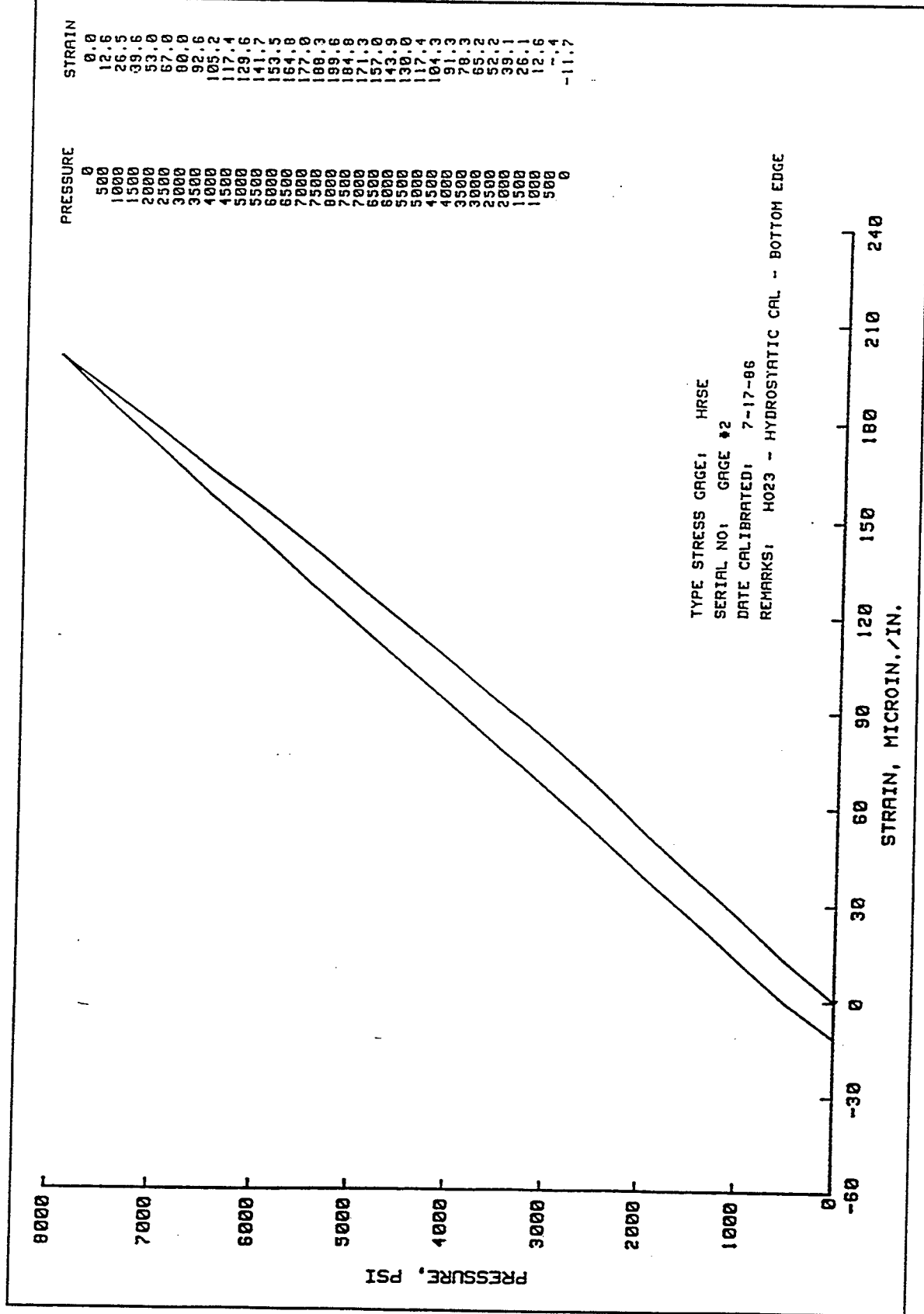
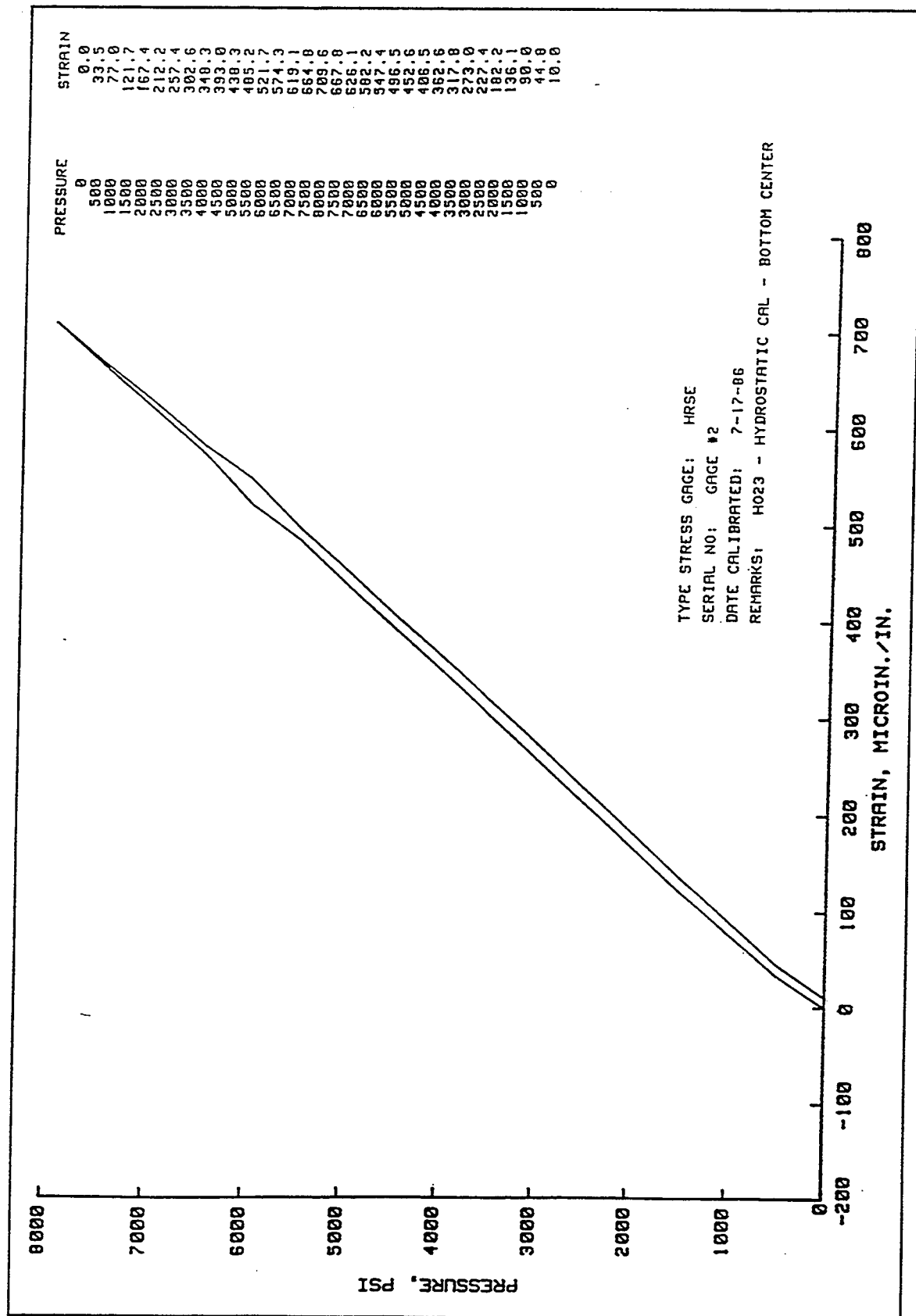
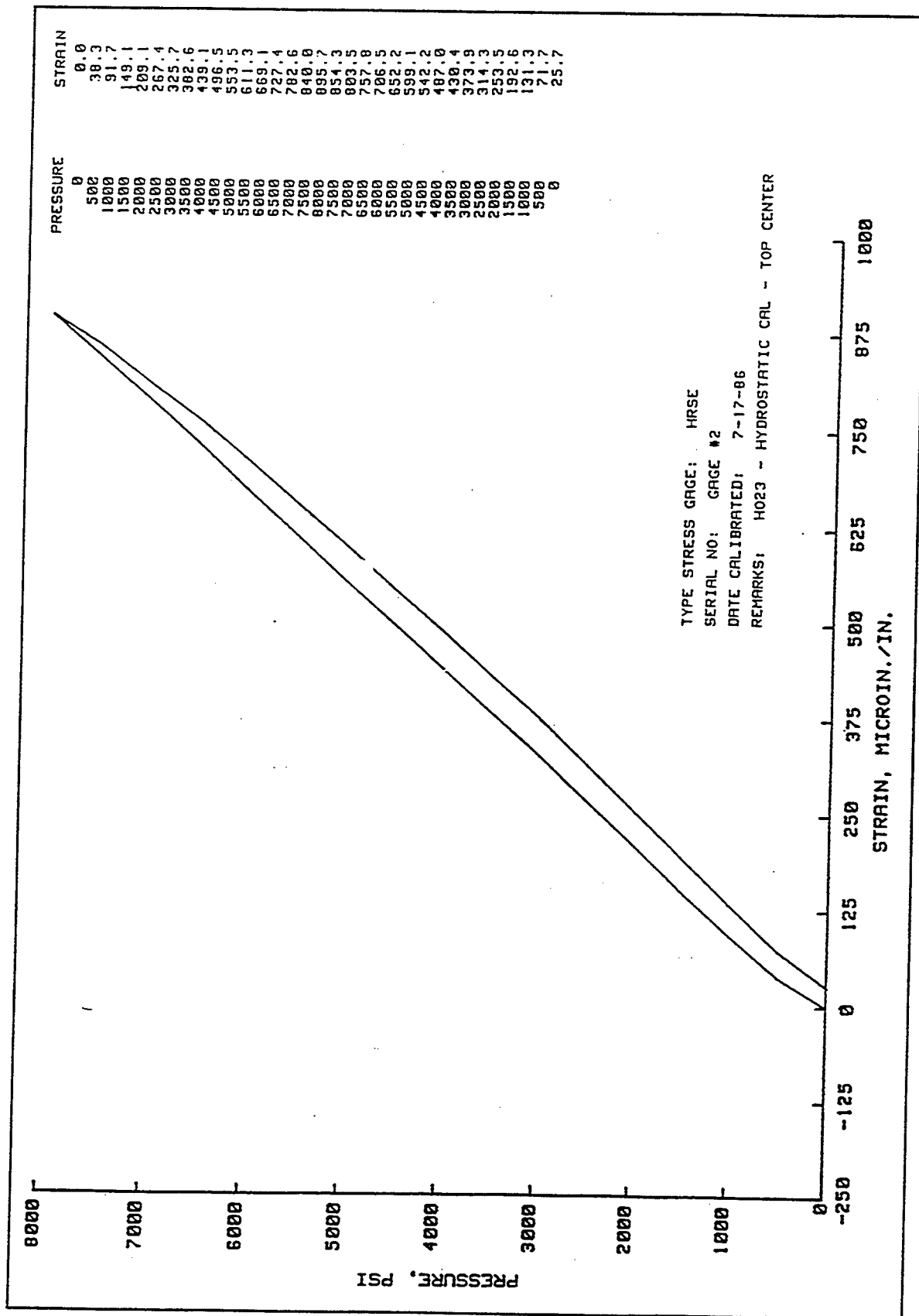
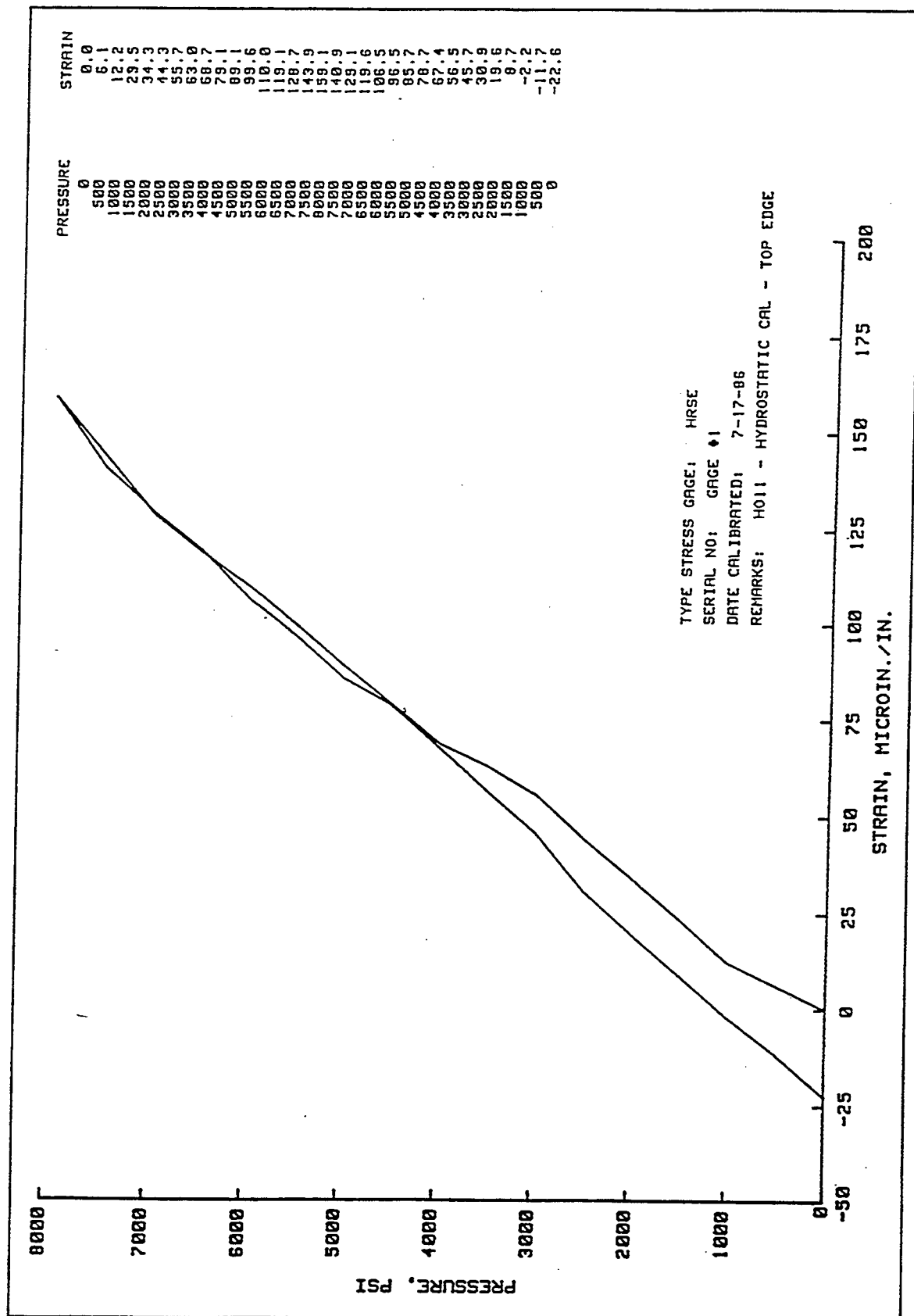


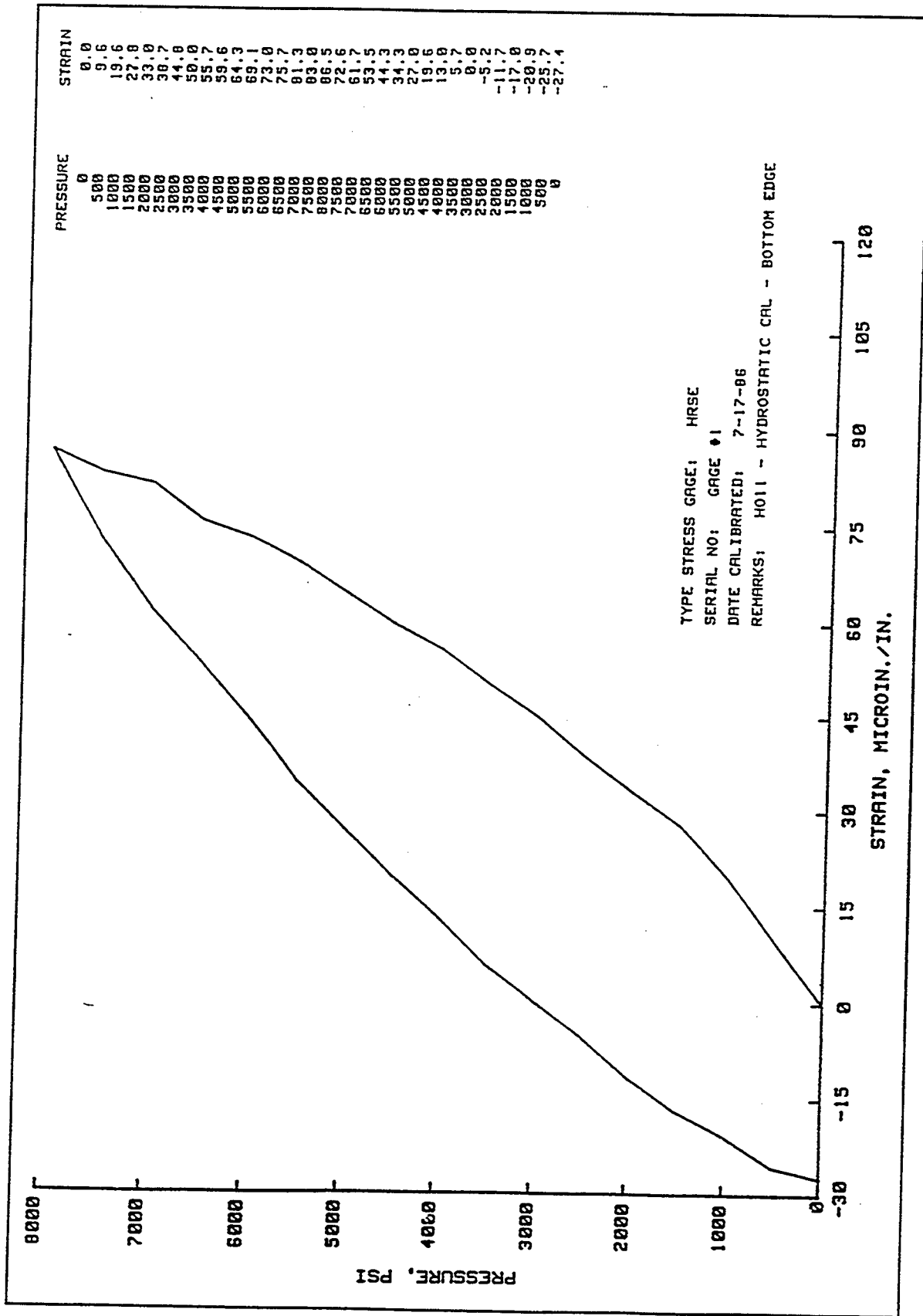
Plate 56

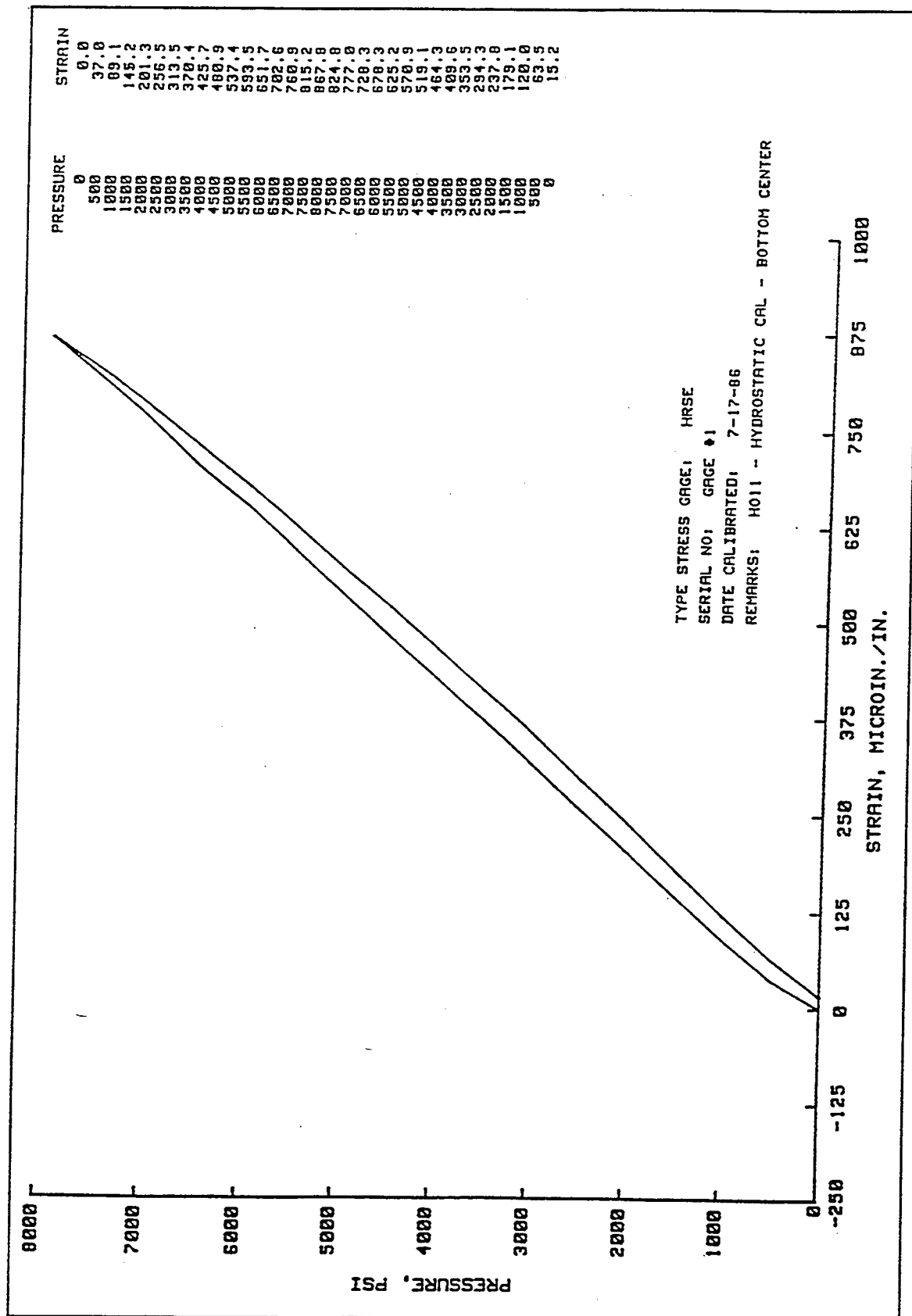


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 REMARKS: H023 - HYDROSTATIC CAL - BOTTOM CENTER

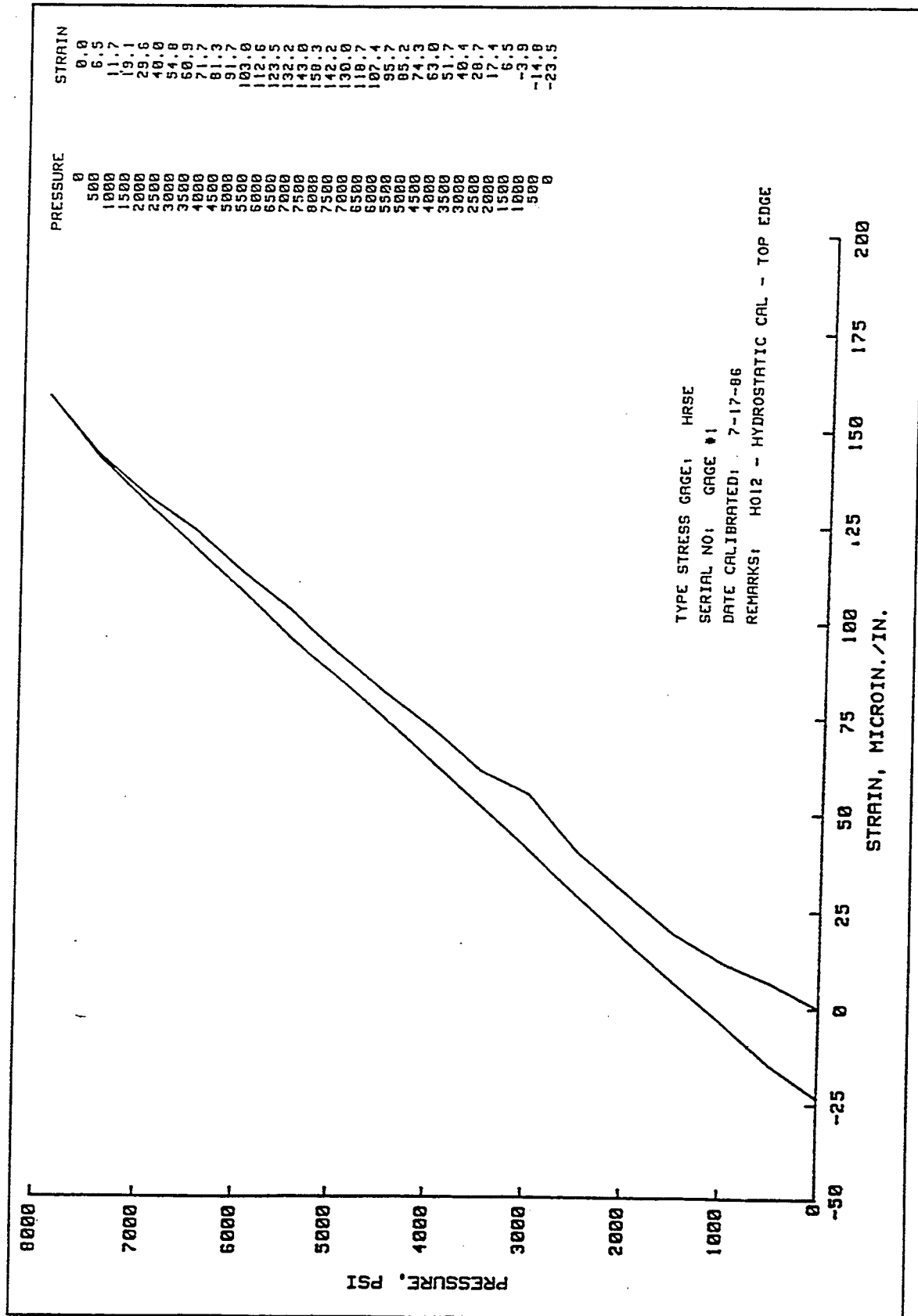




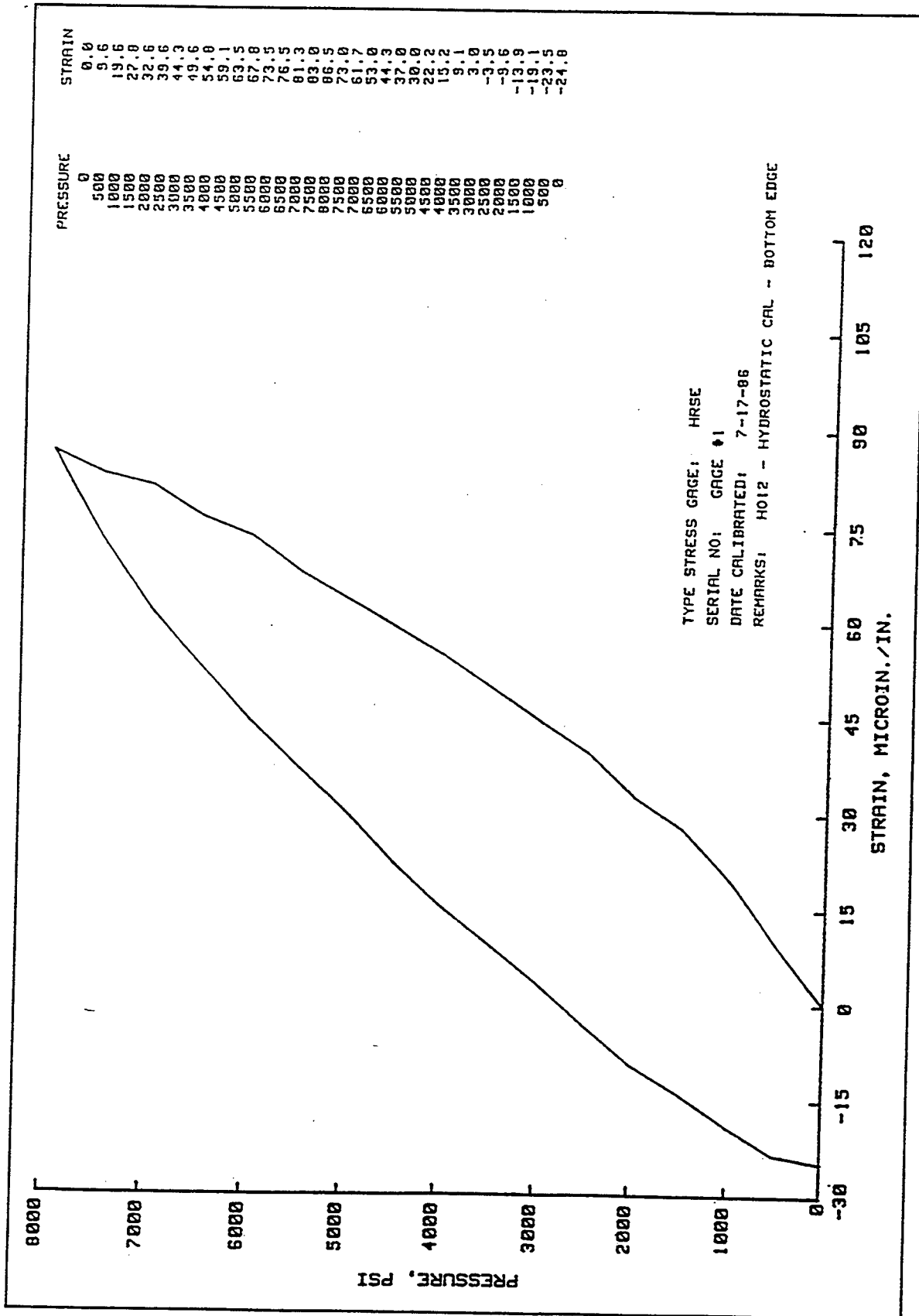


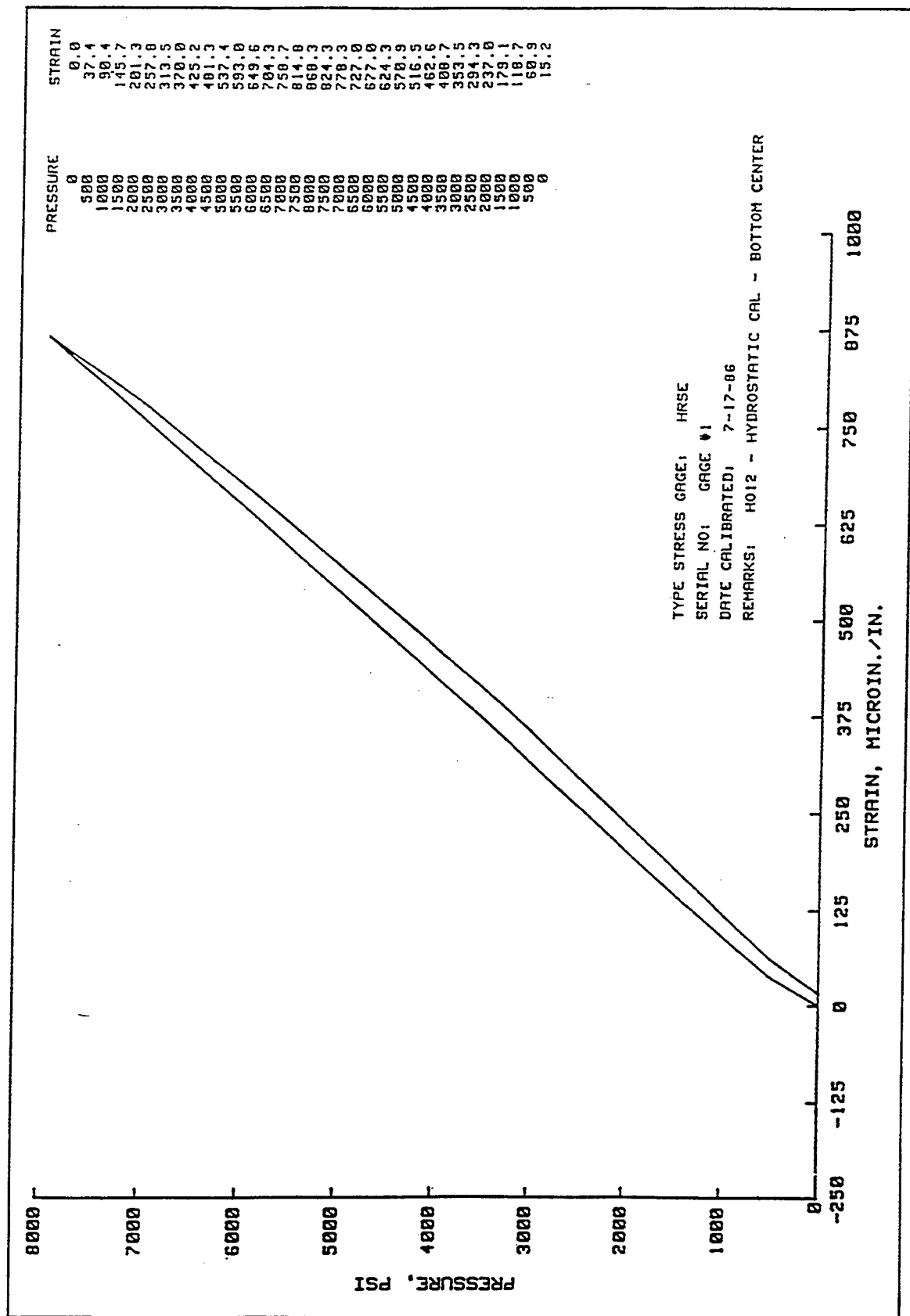












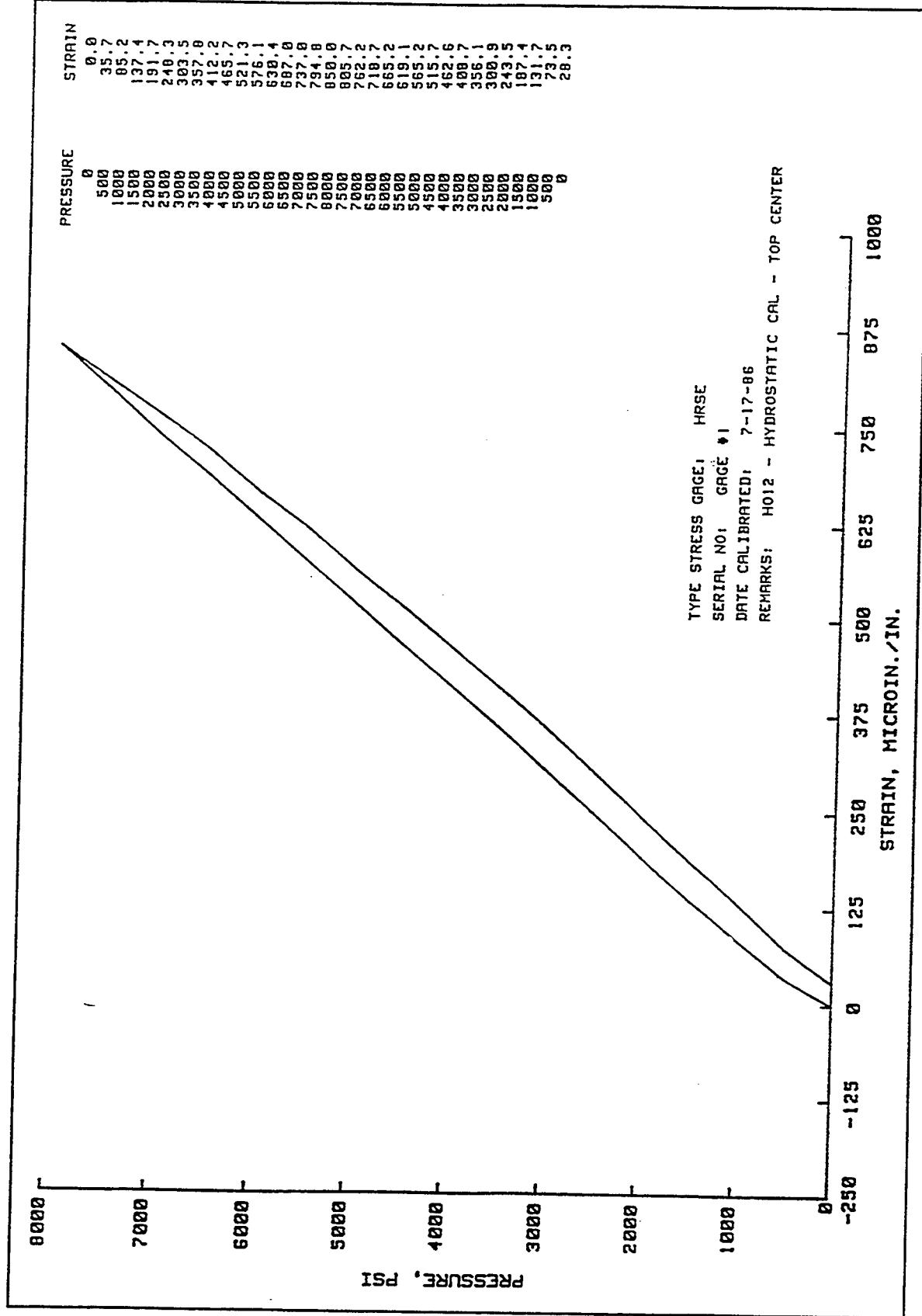
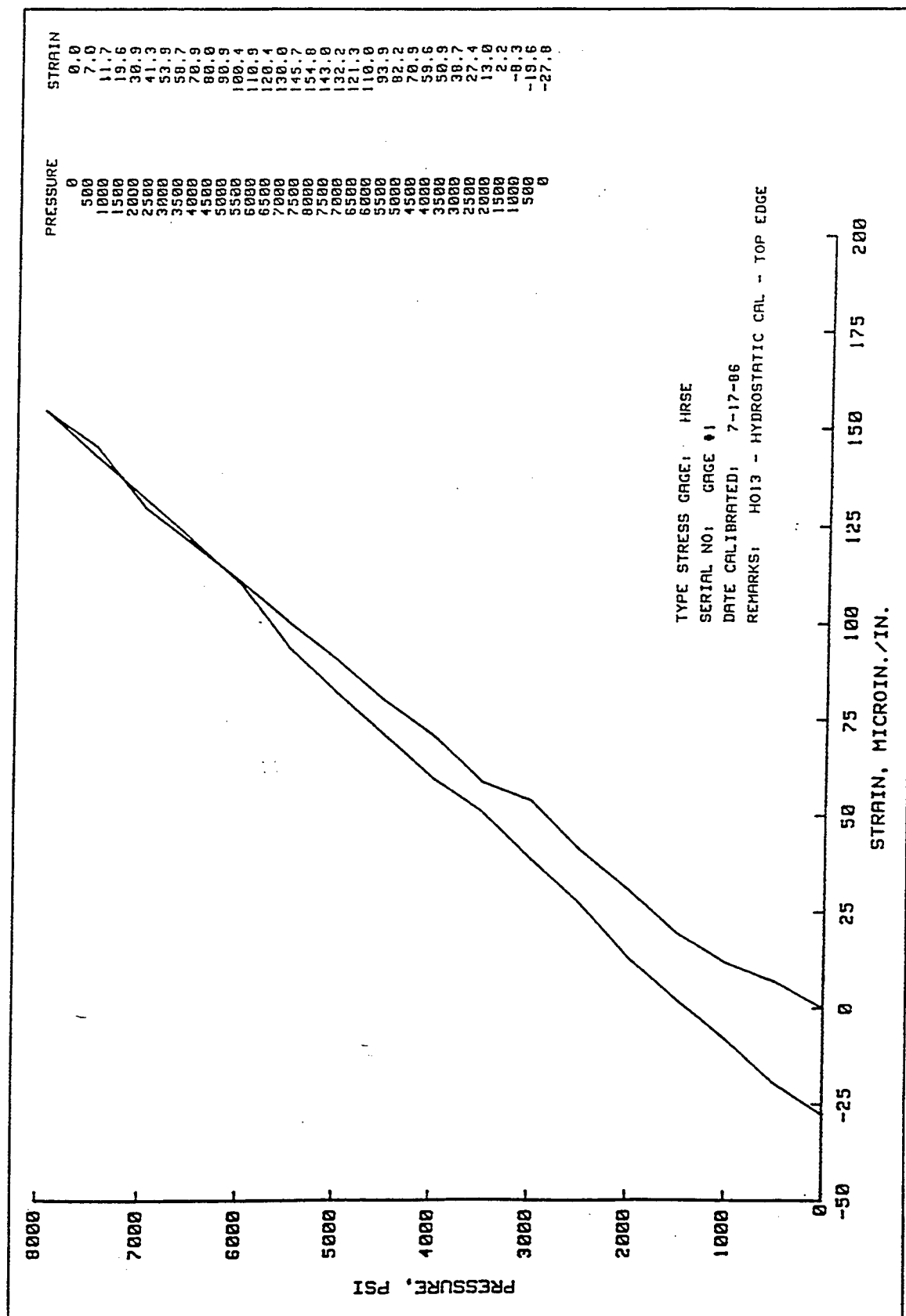
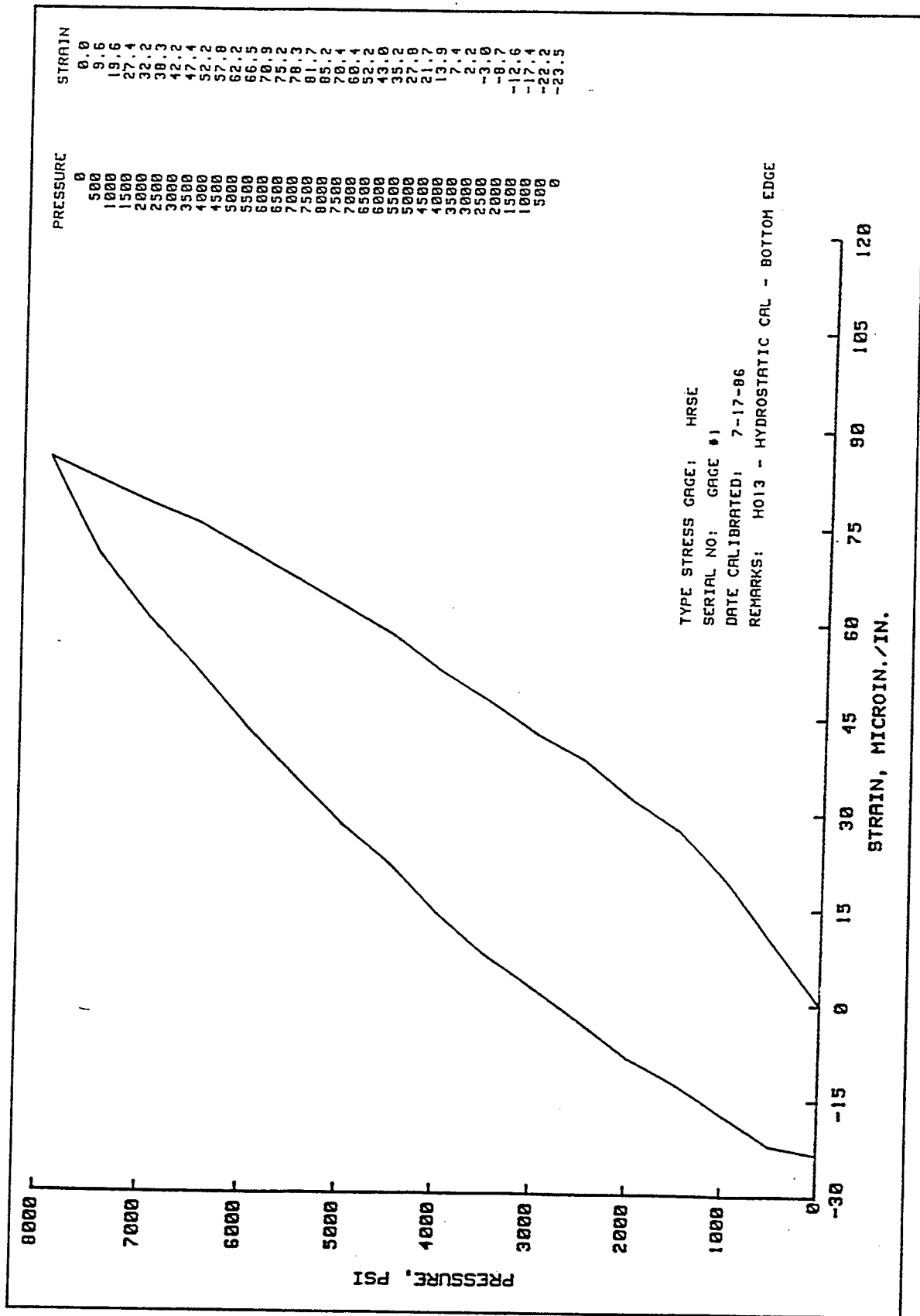
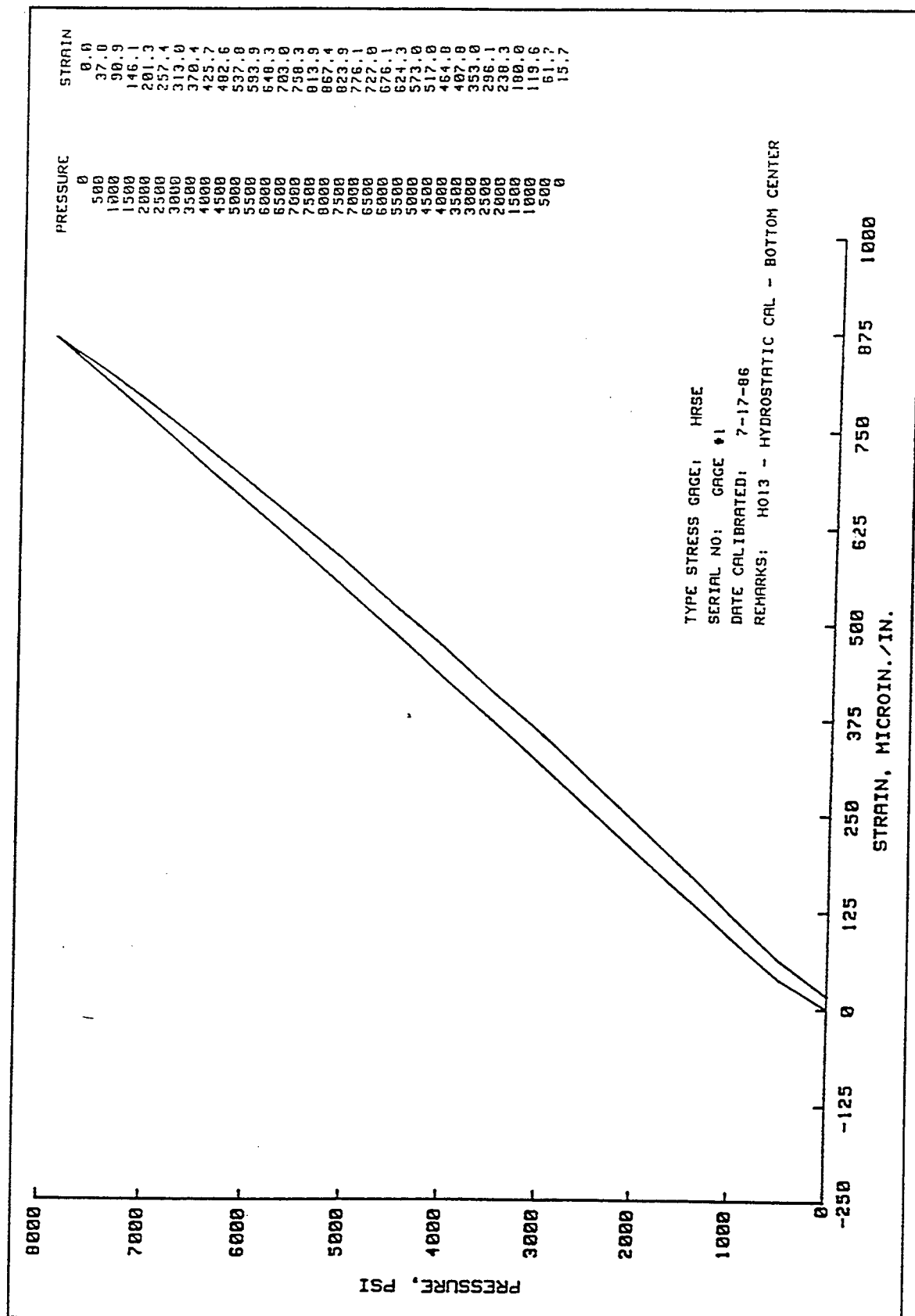
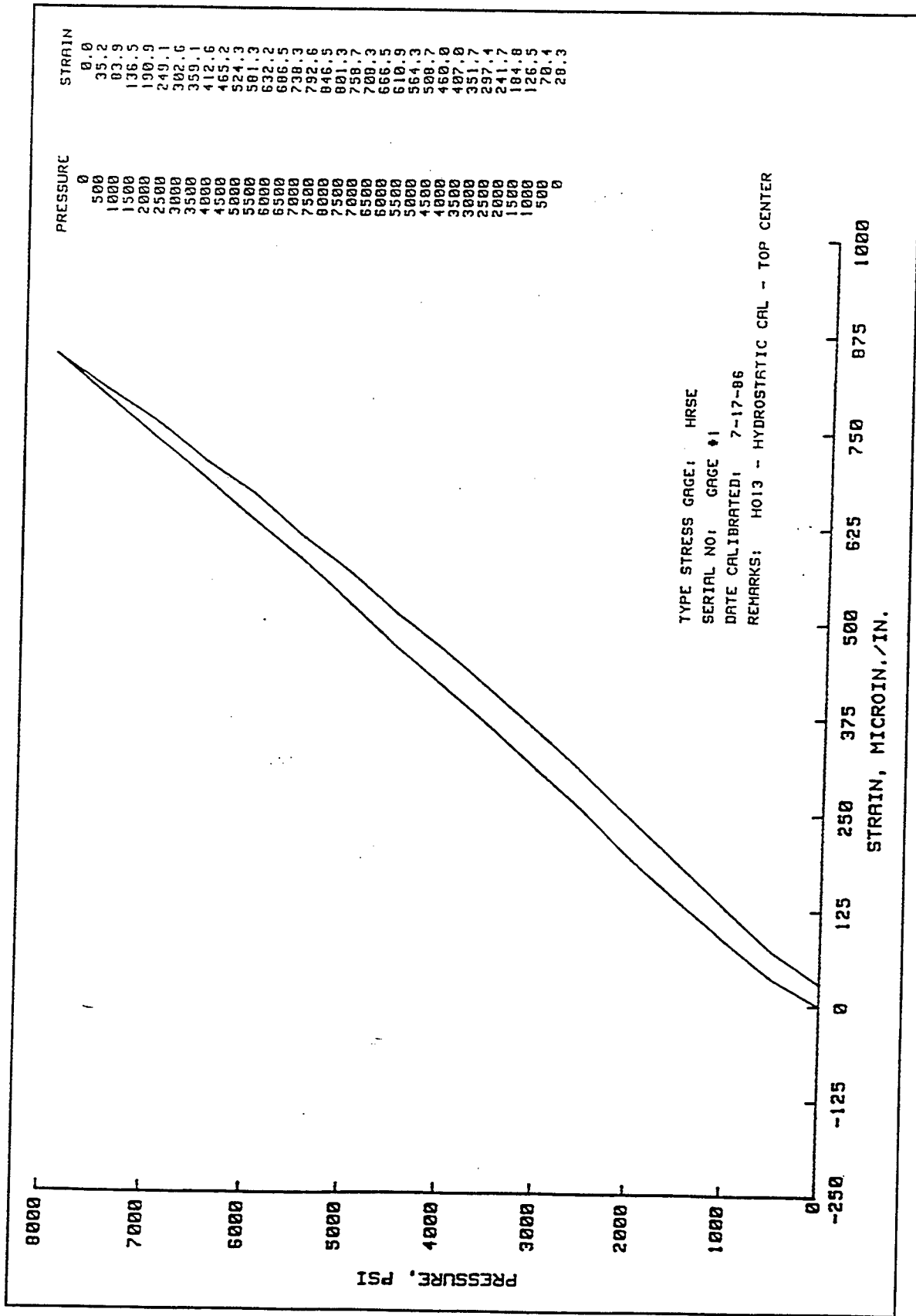


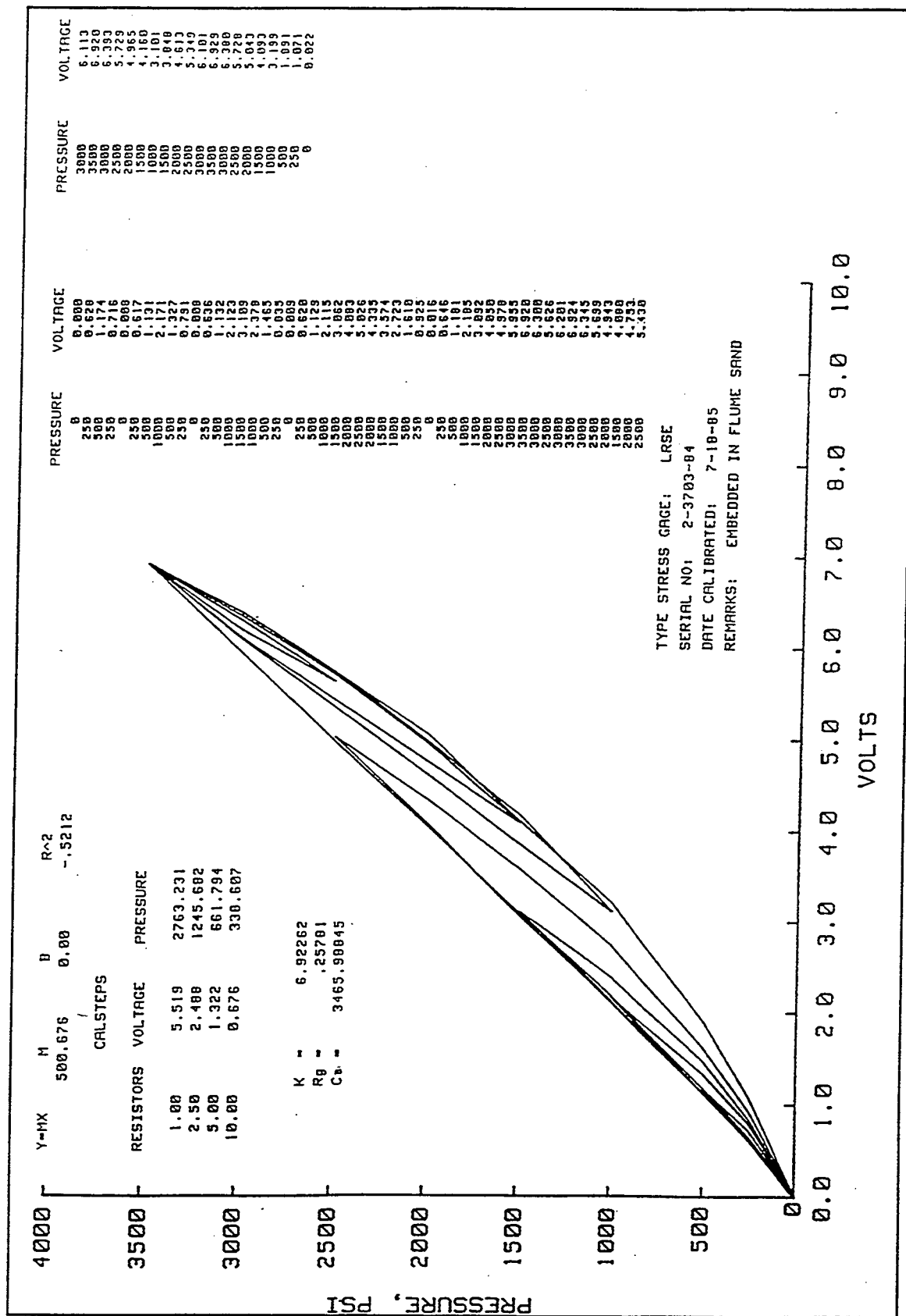
Plate 66



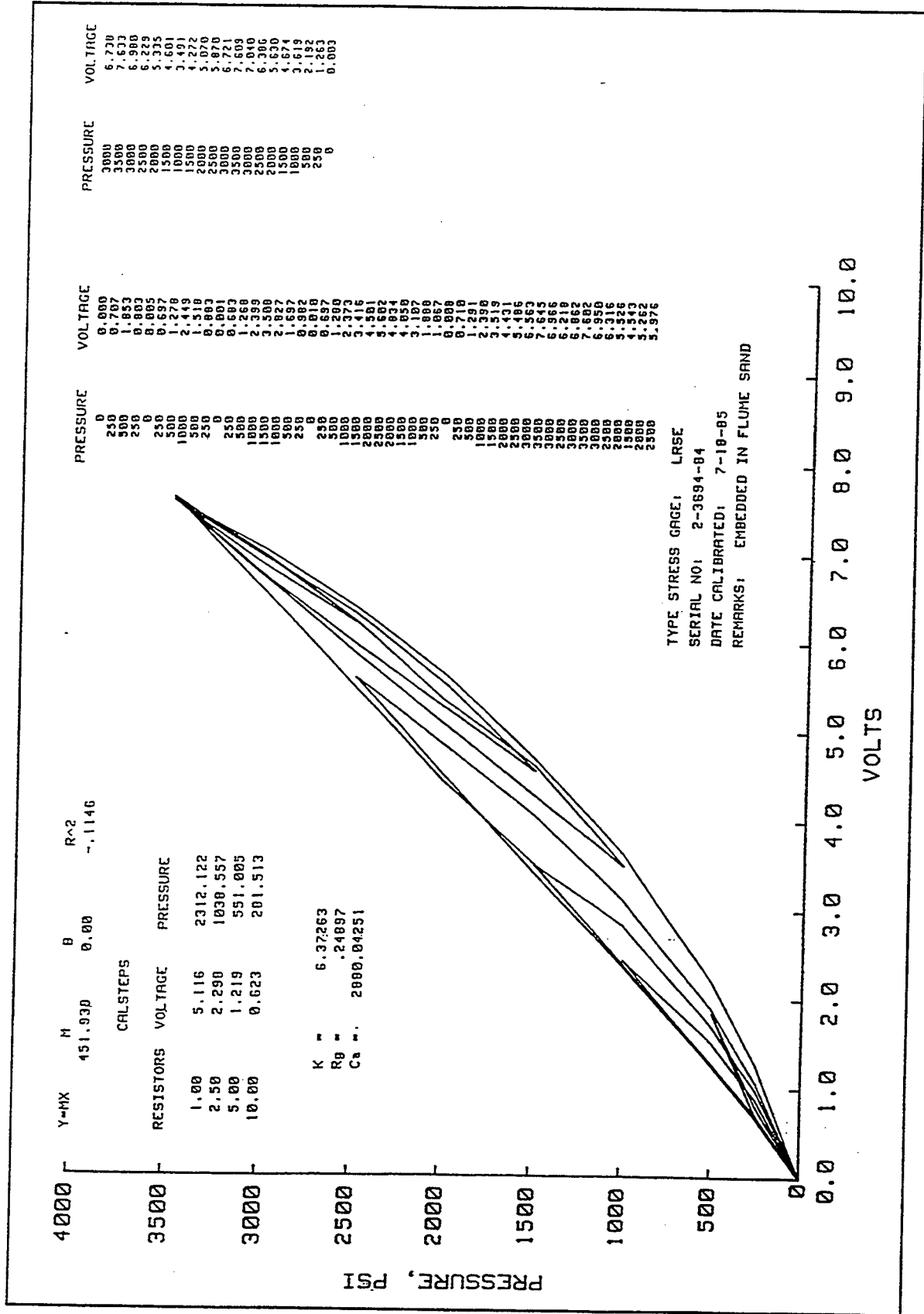


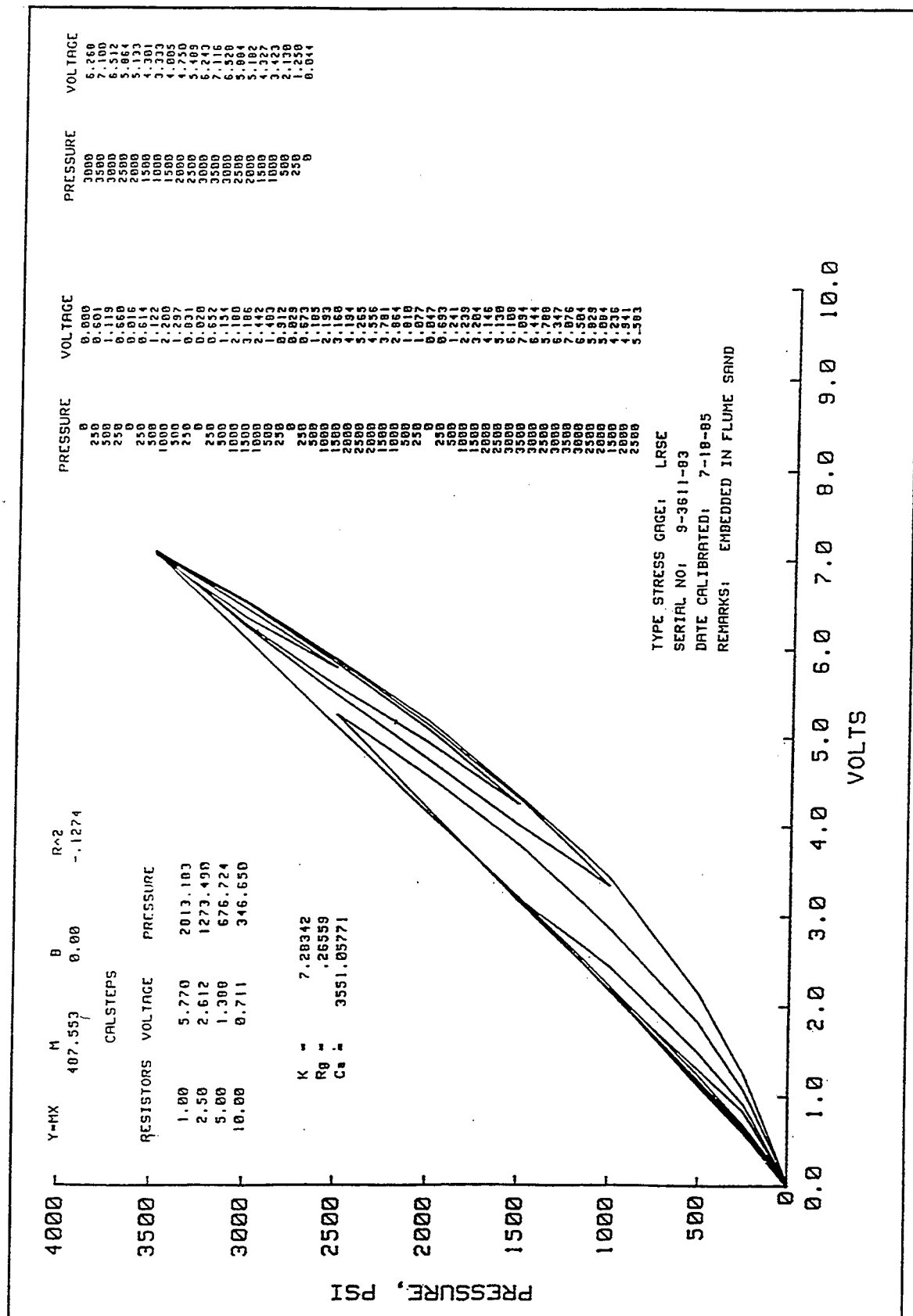


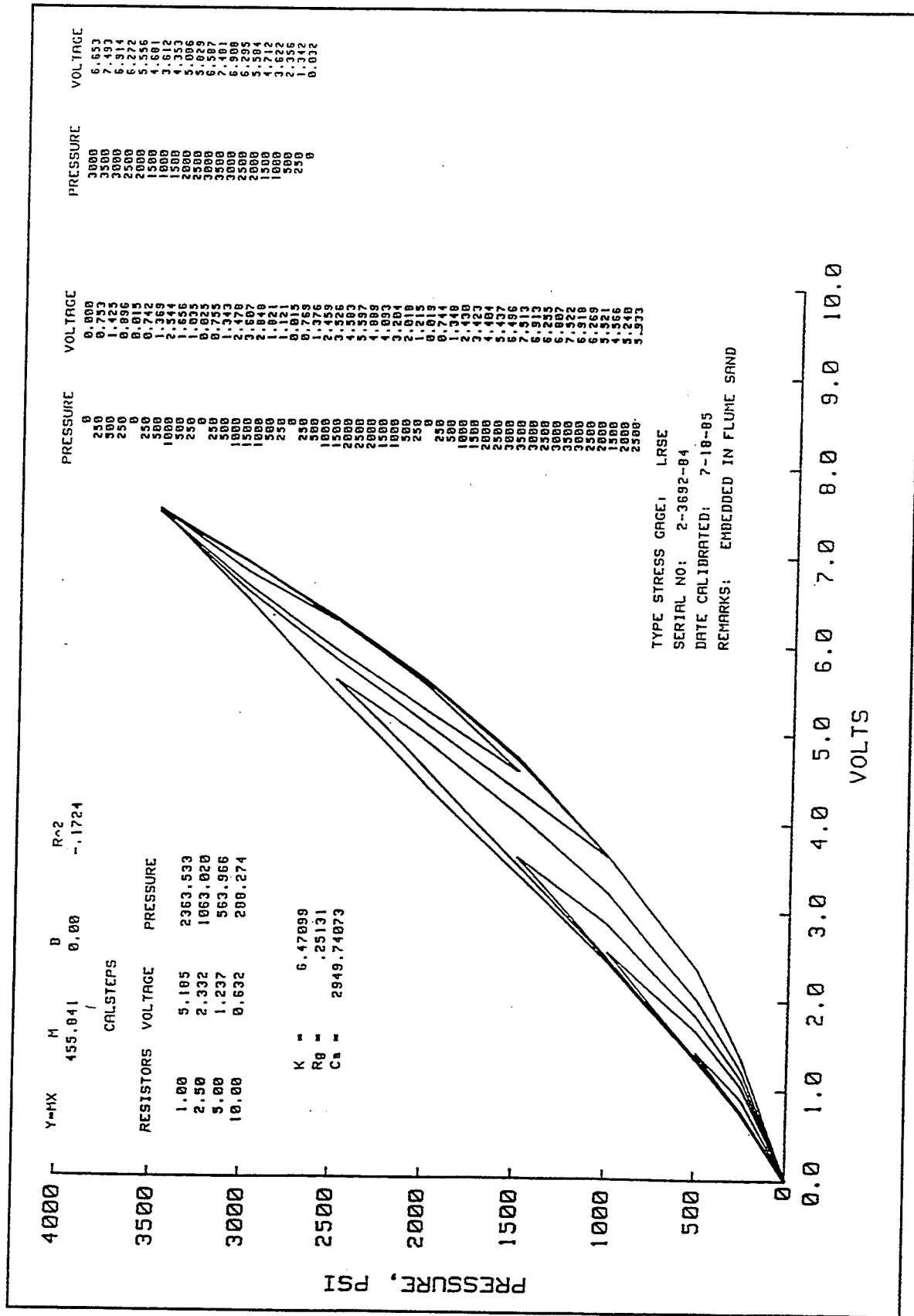


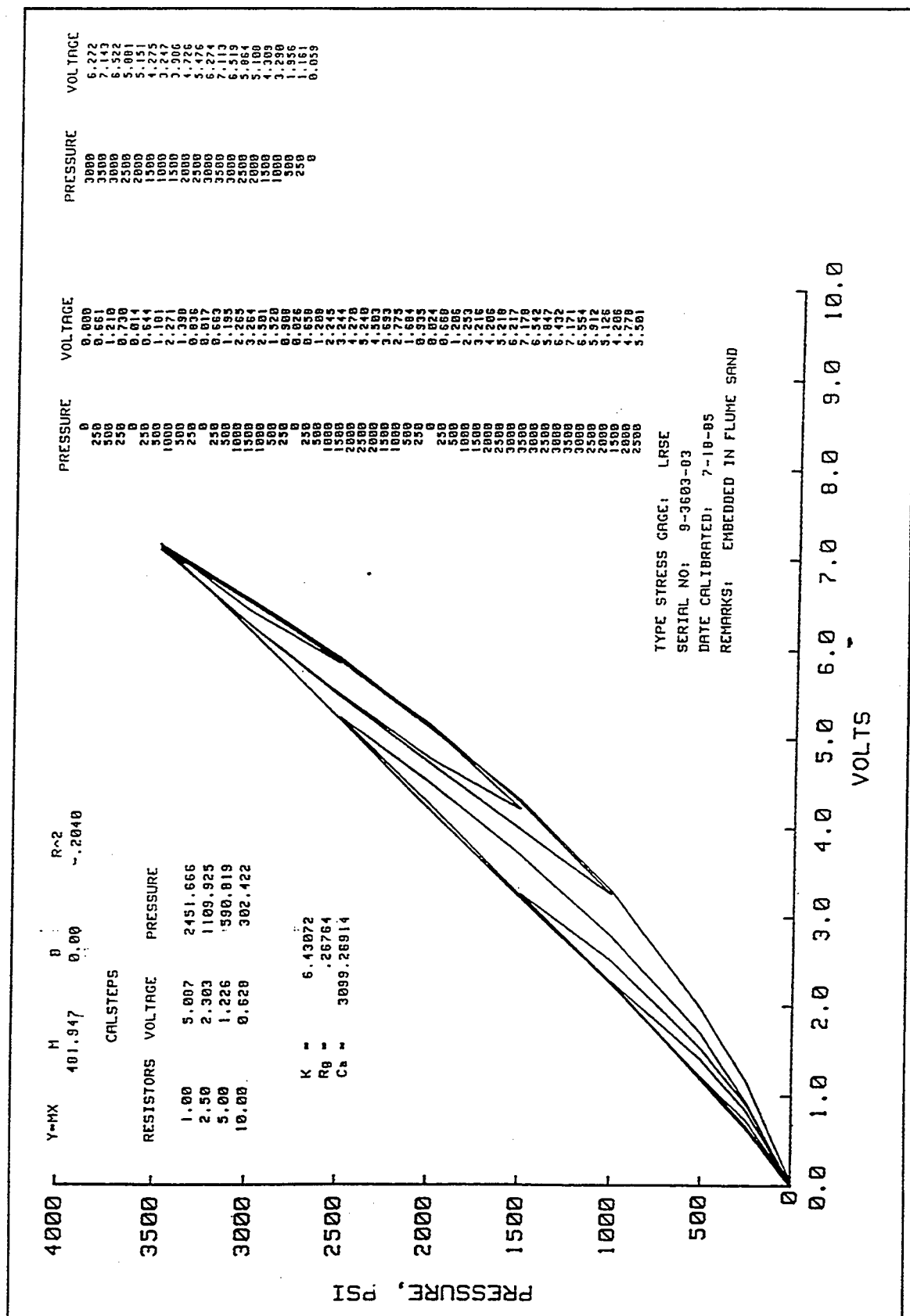


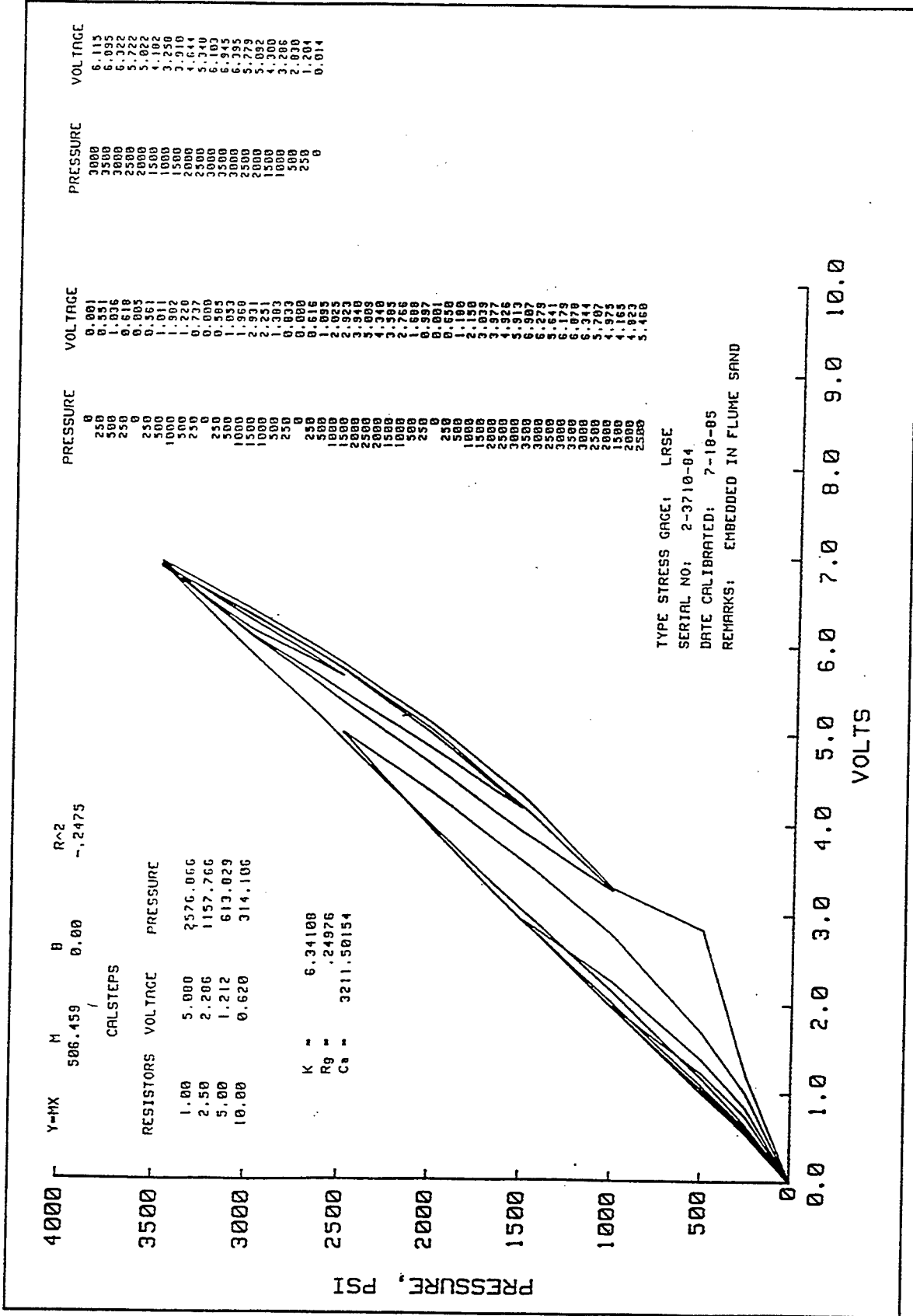


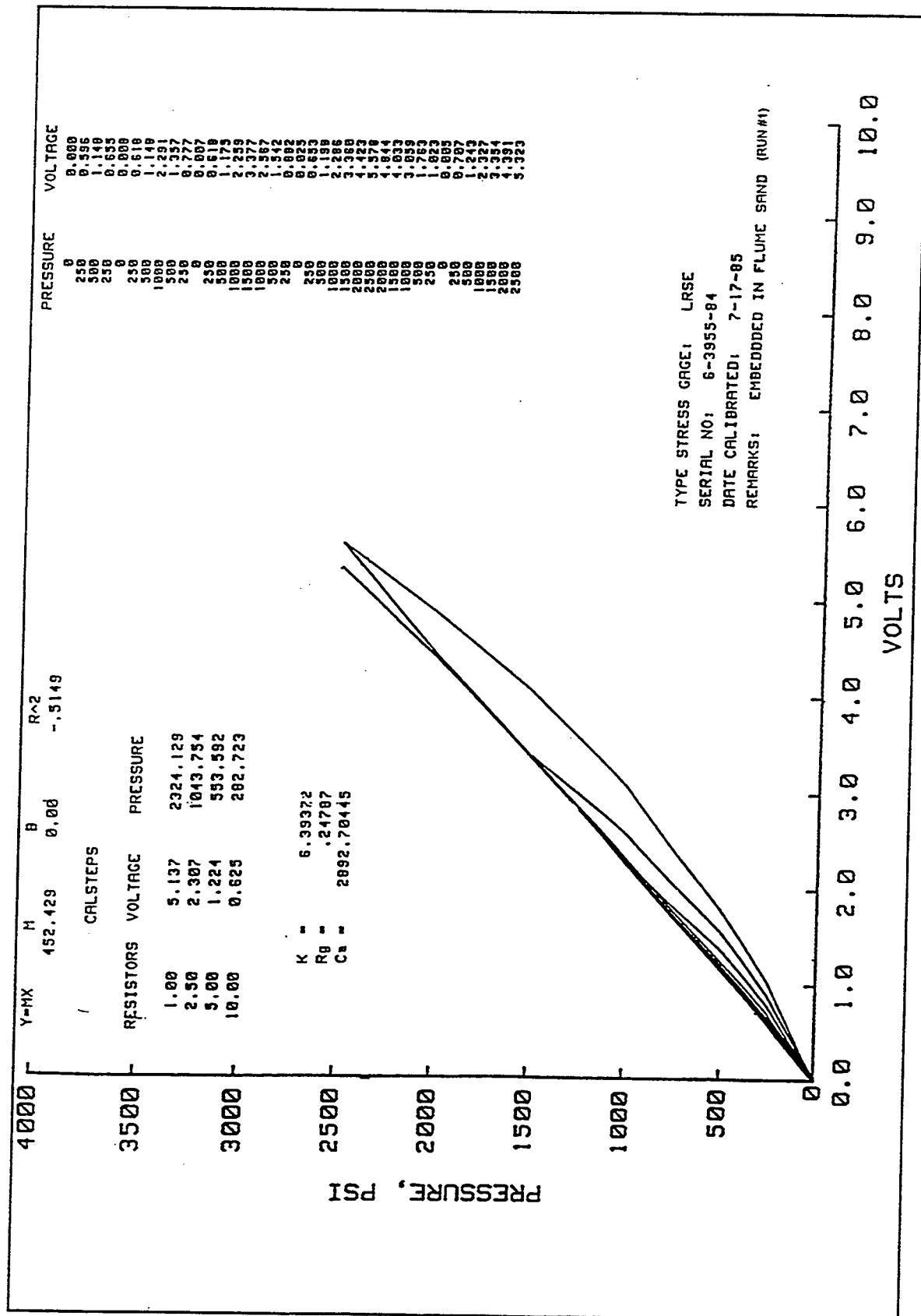


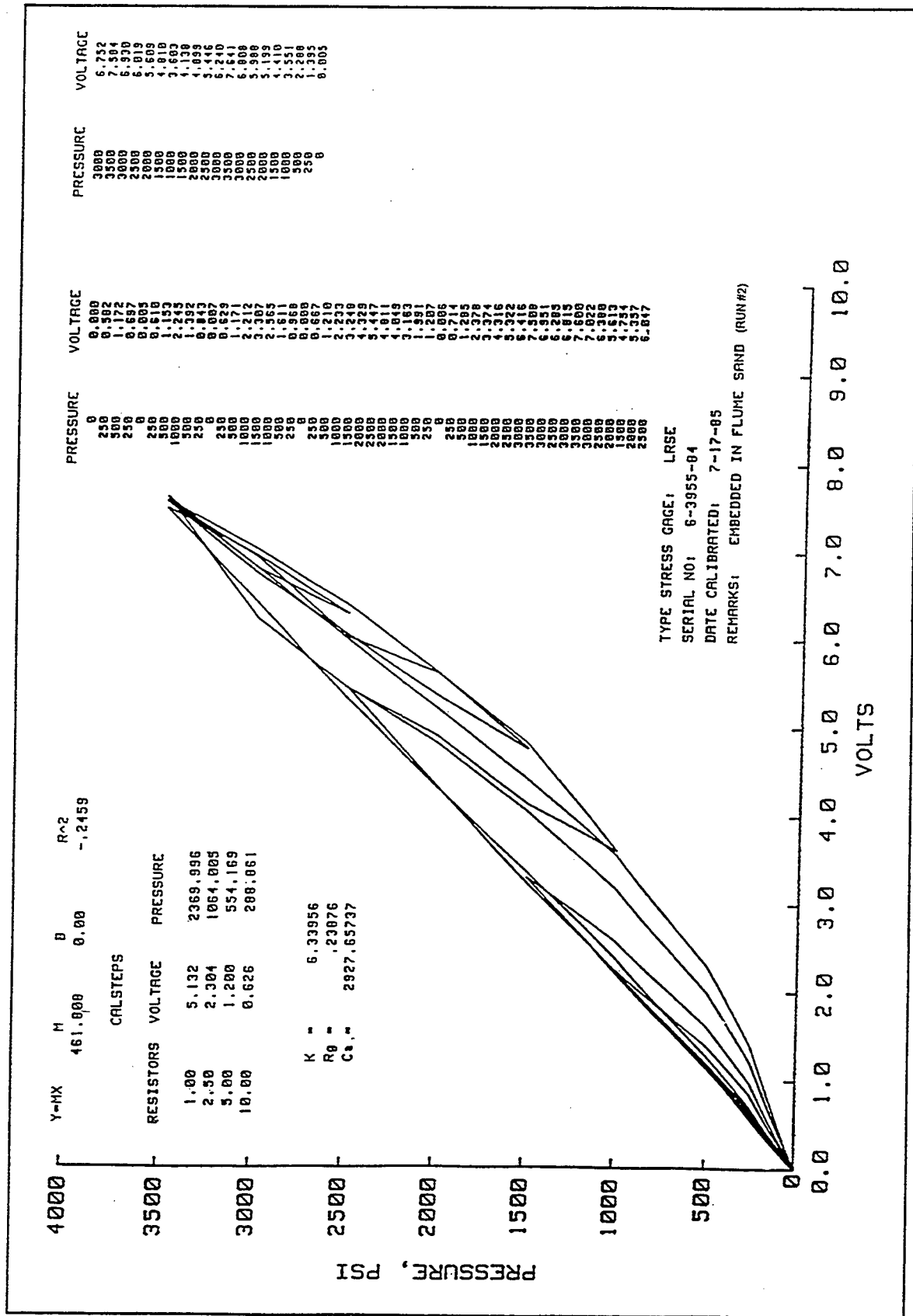


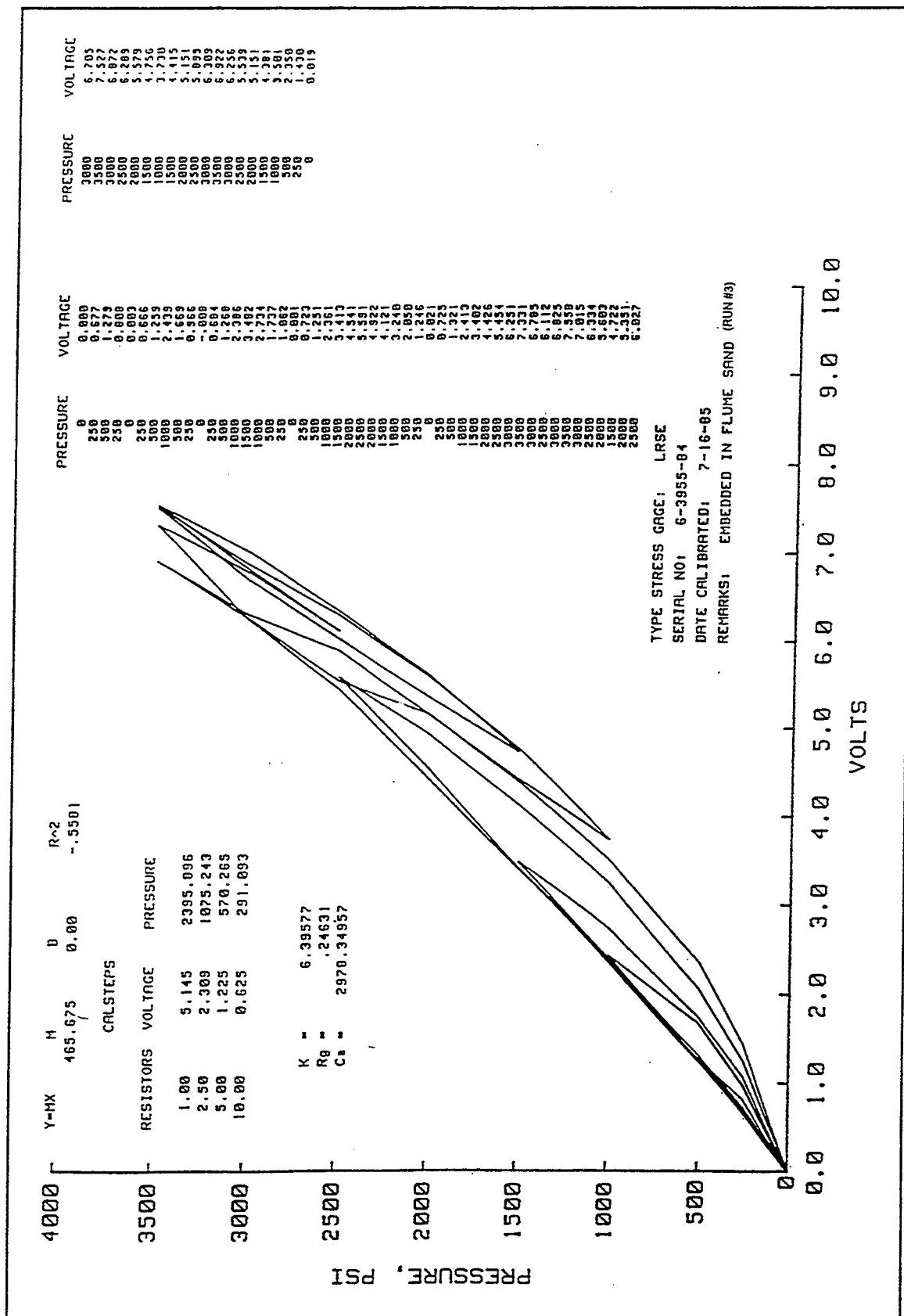




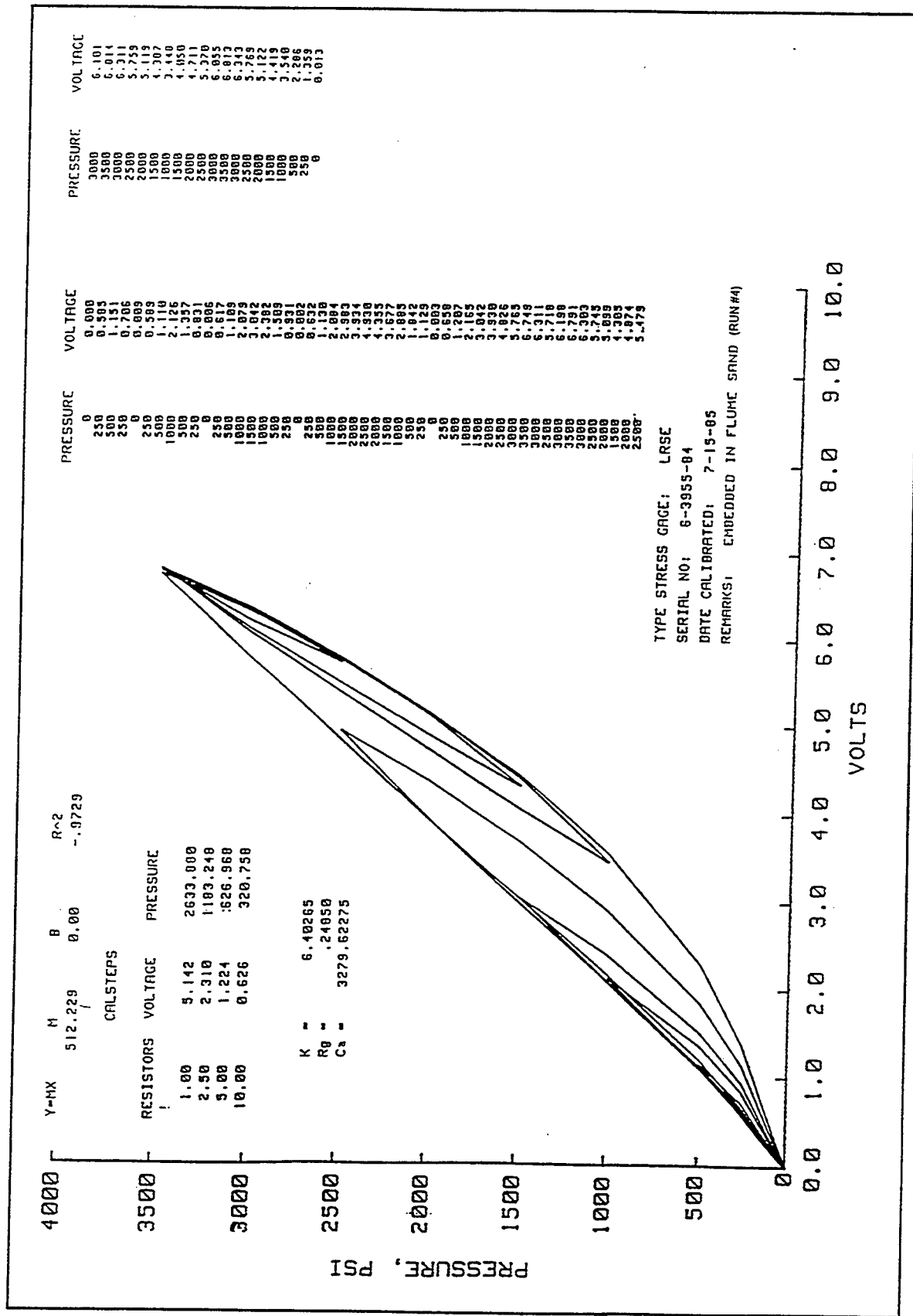


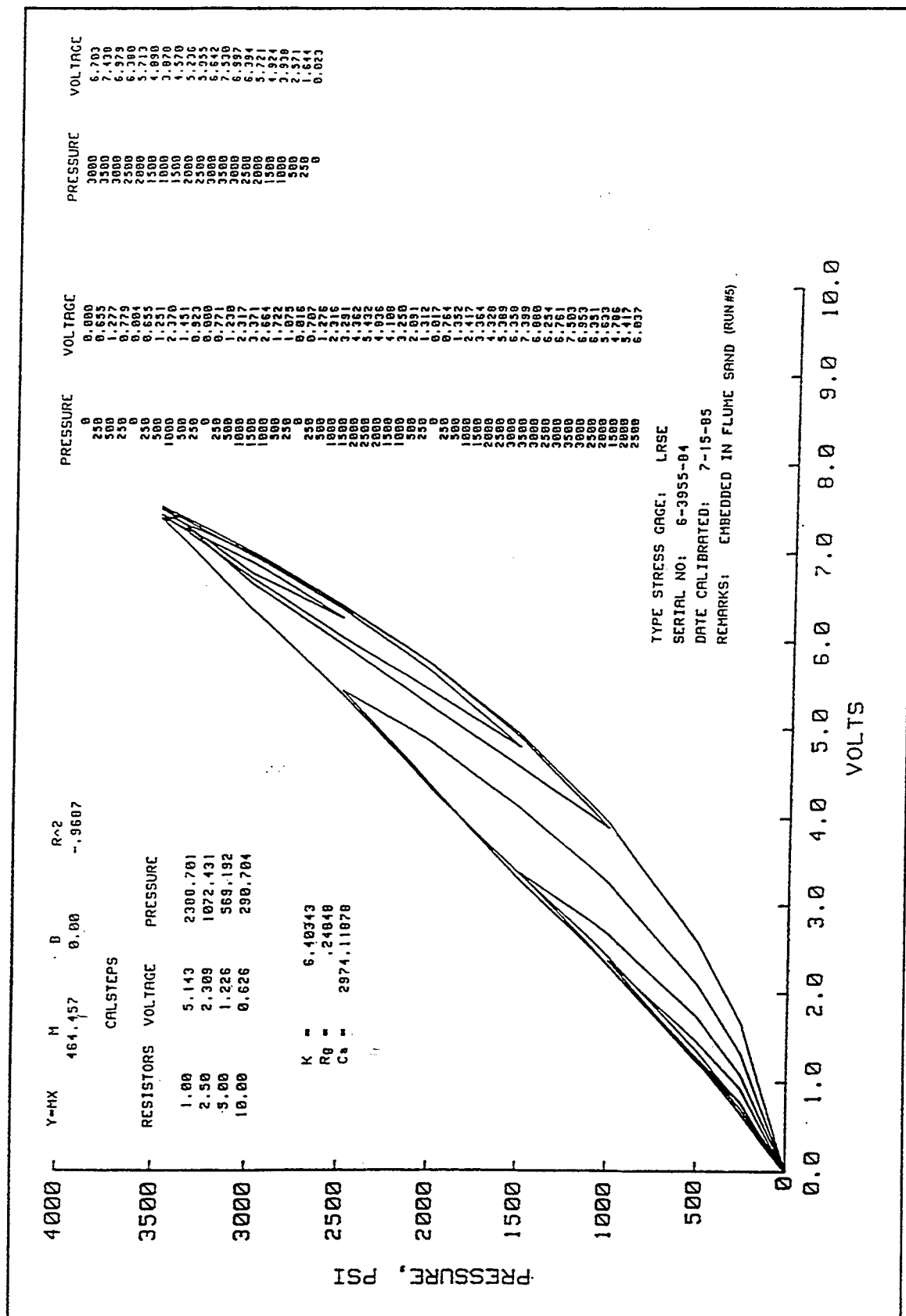


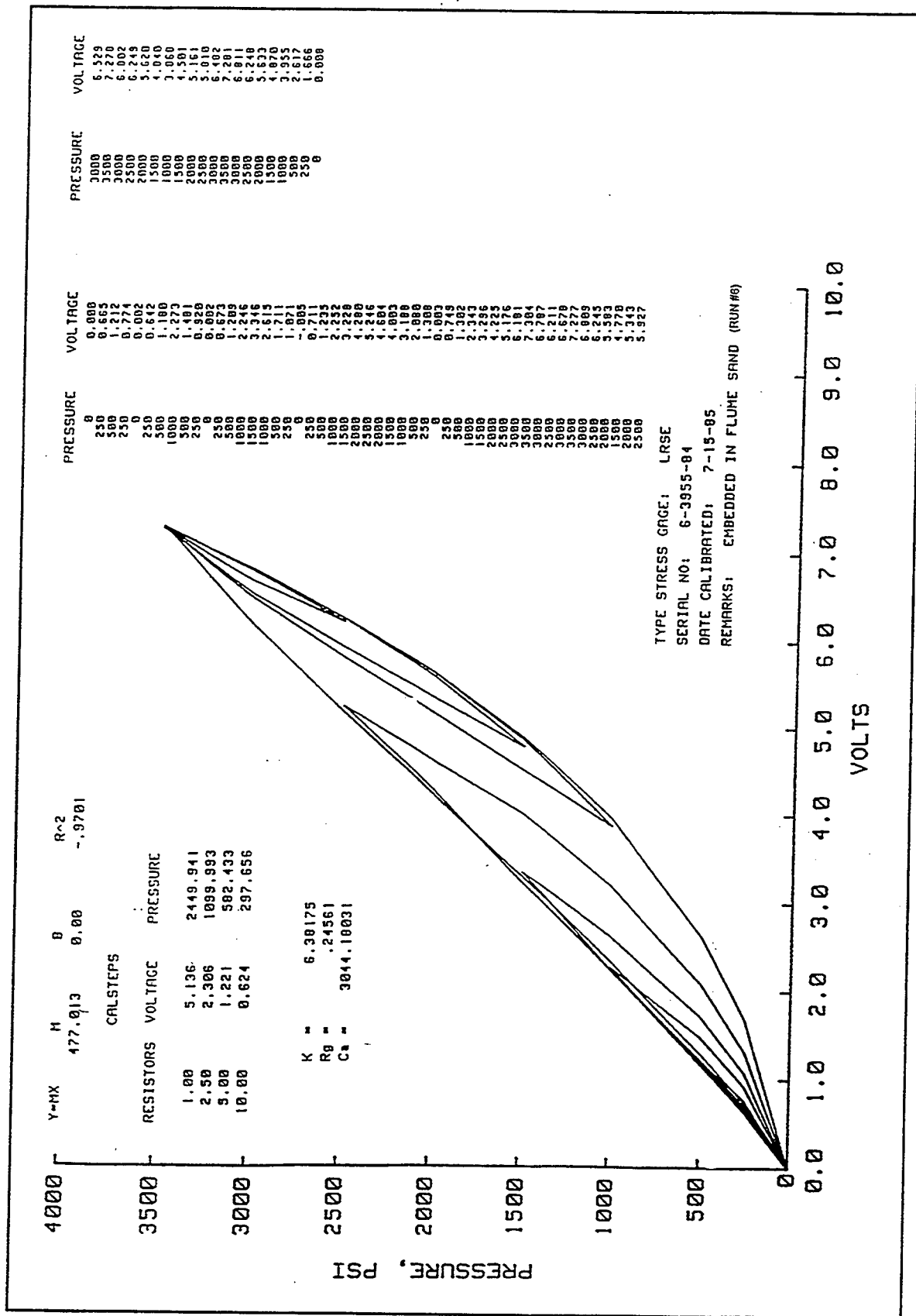


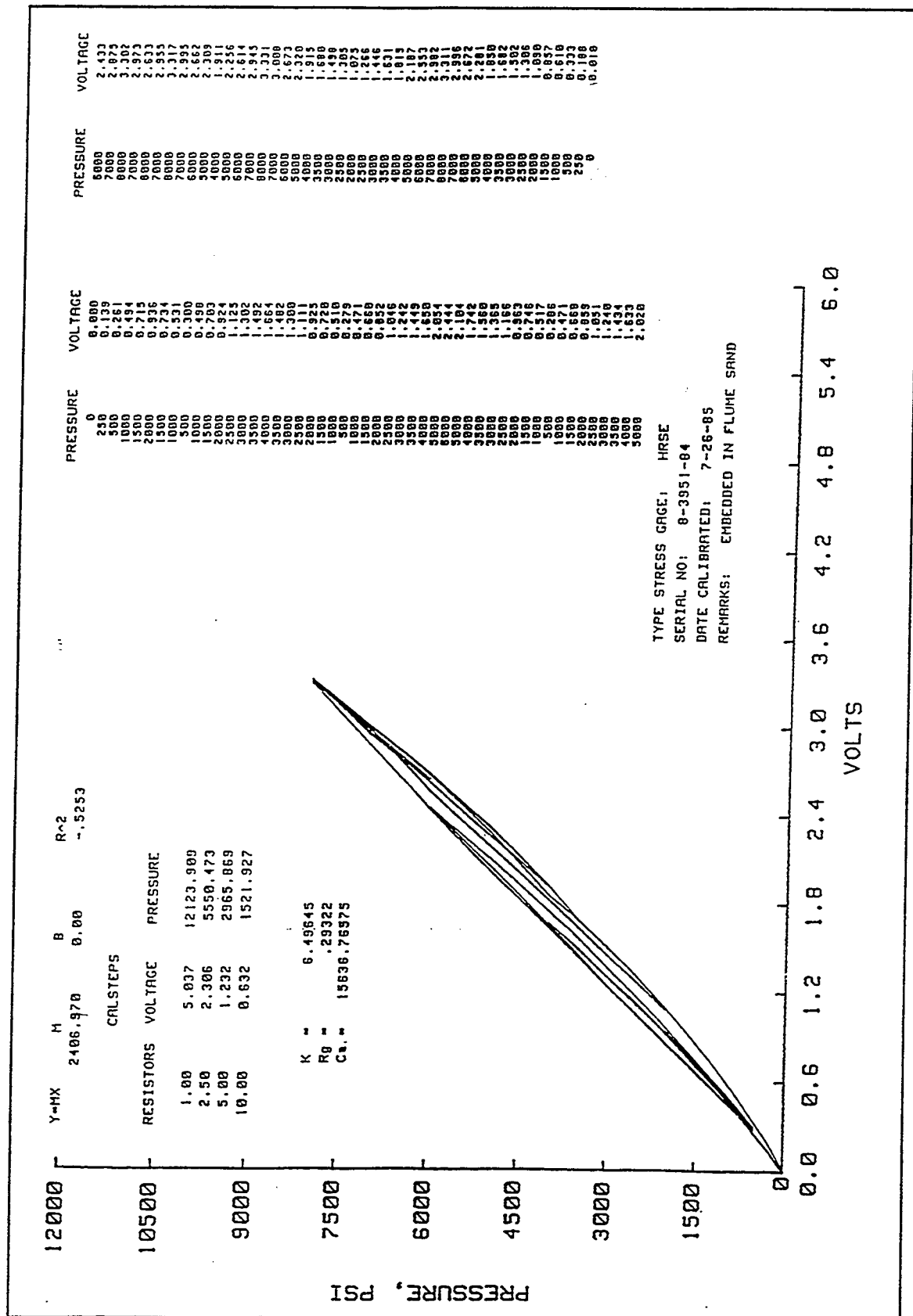


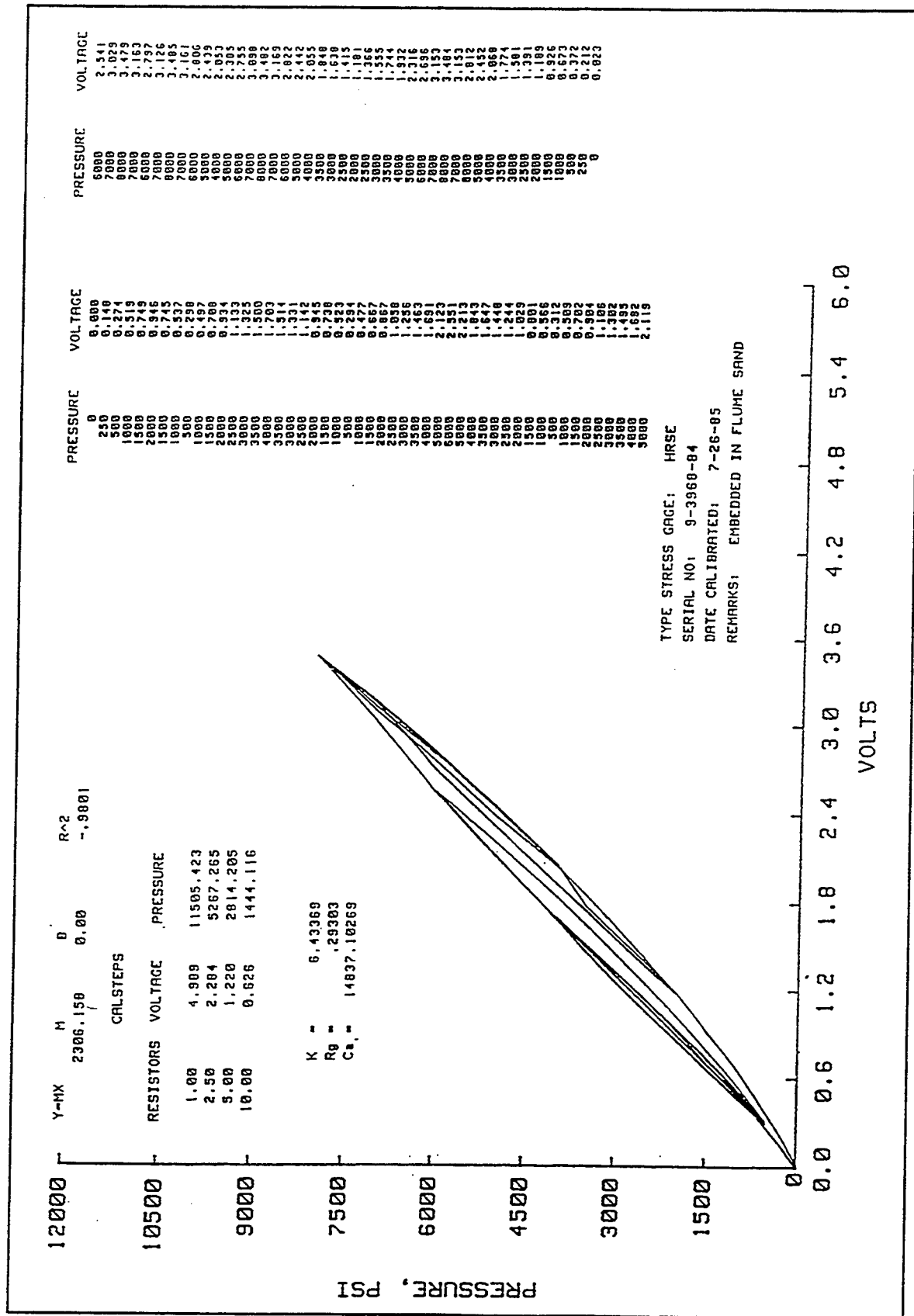


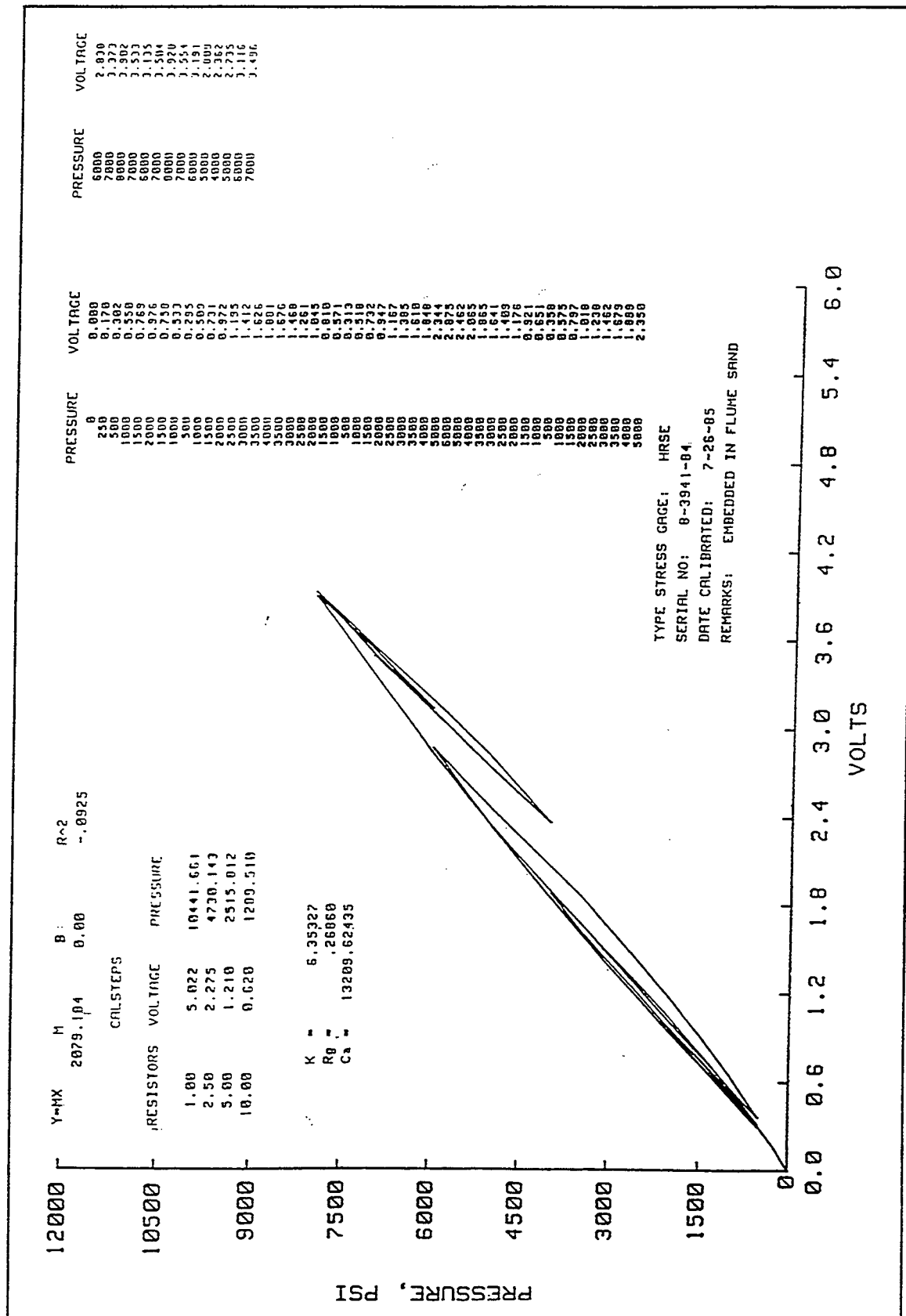


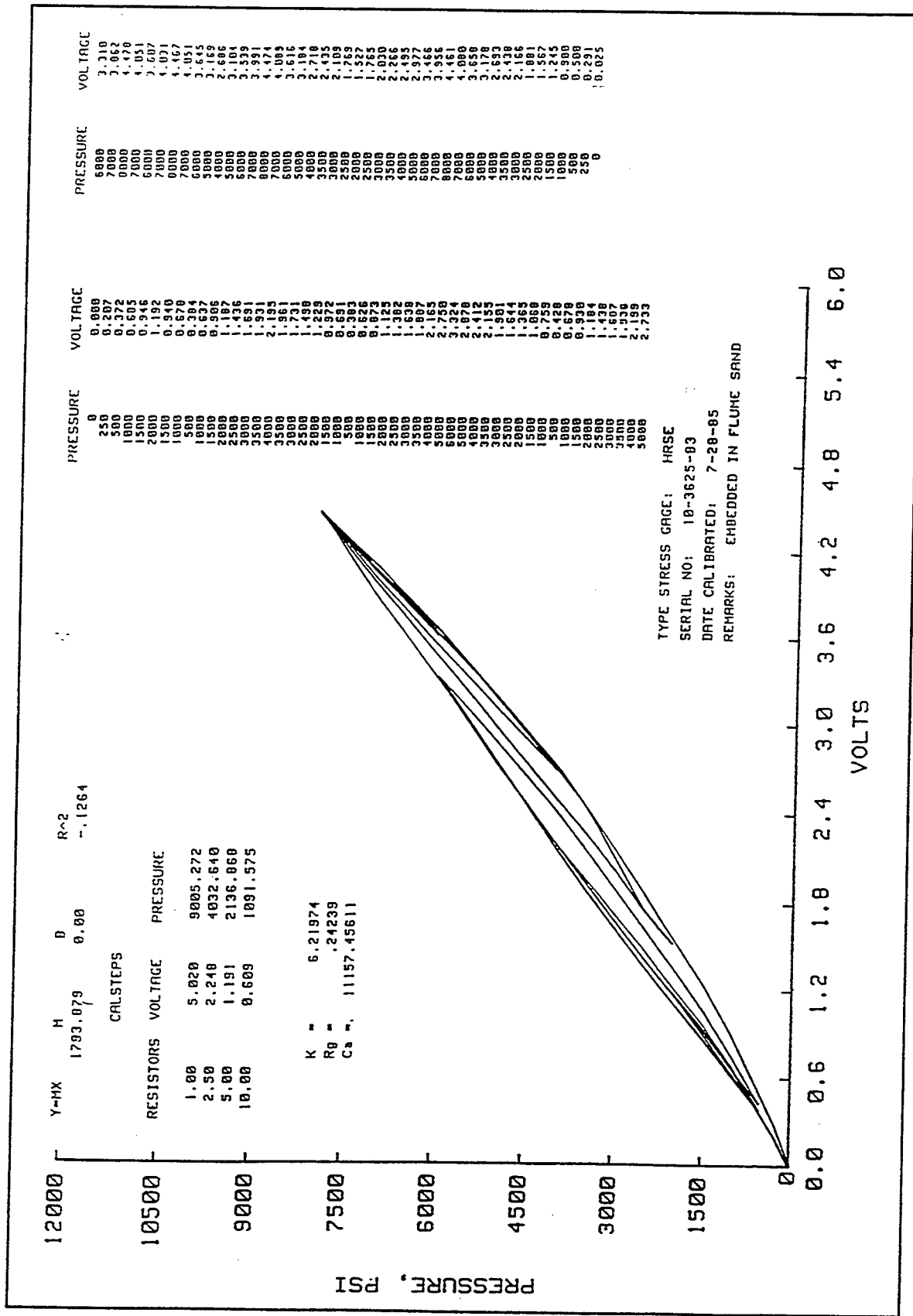


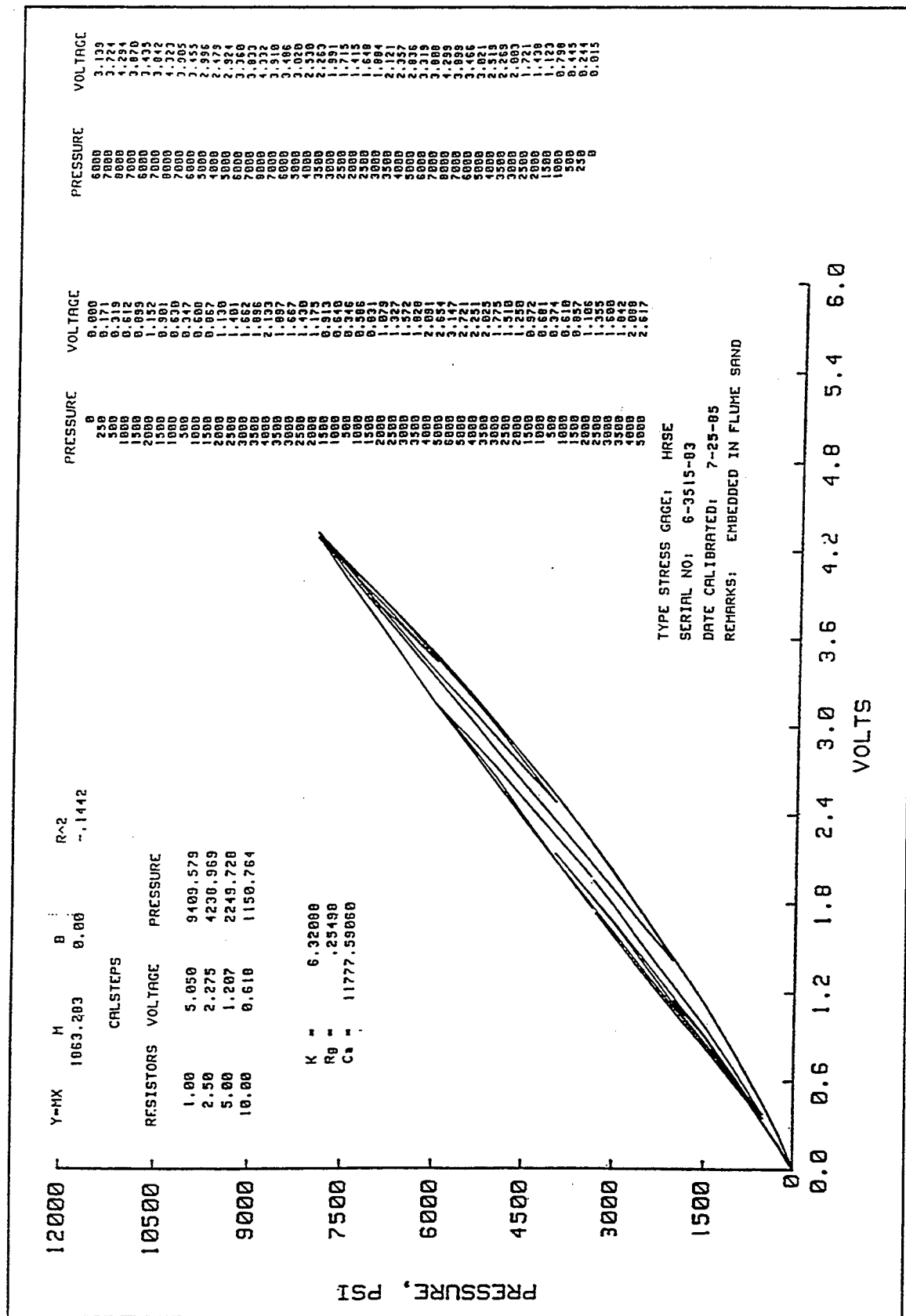




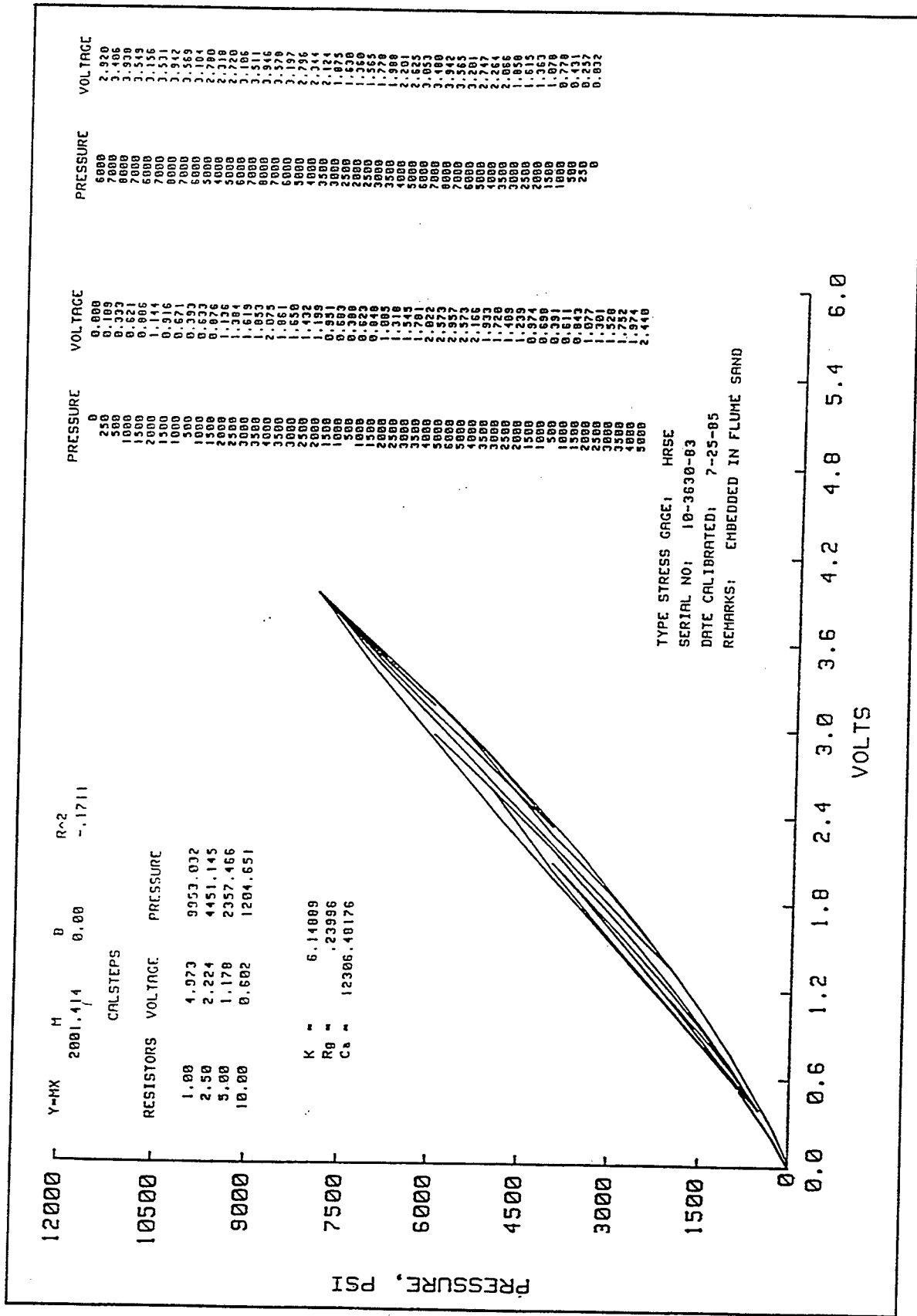


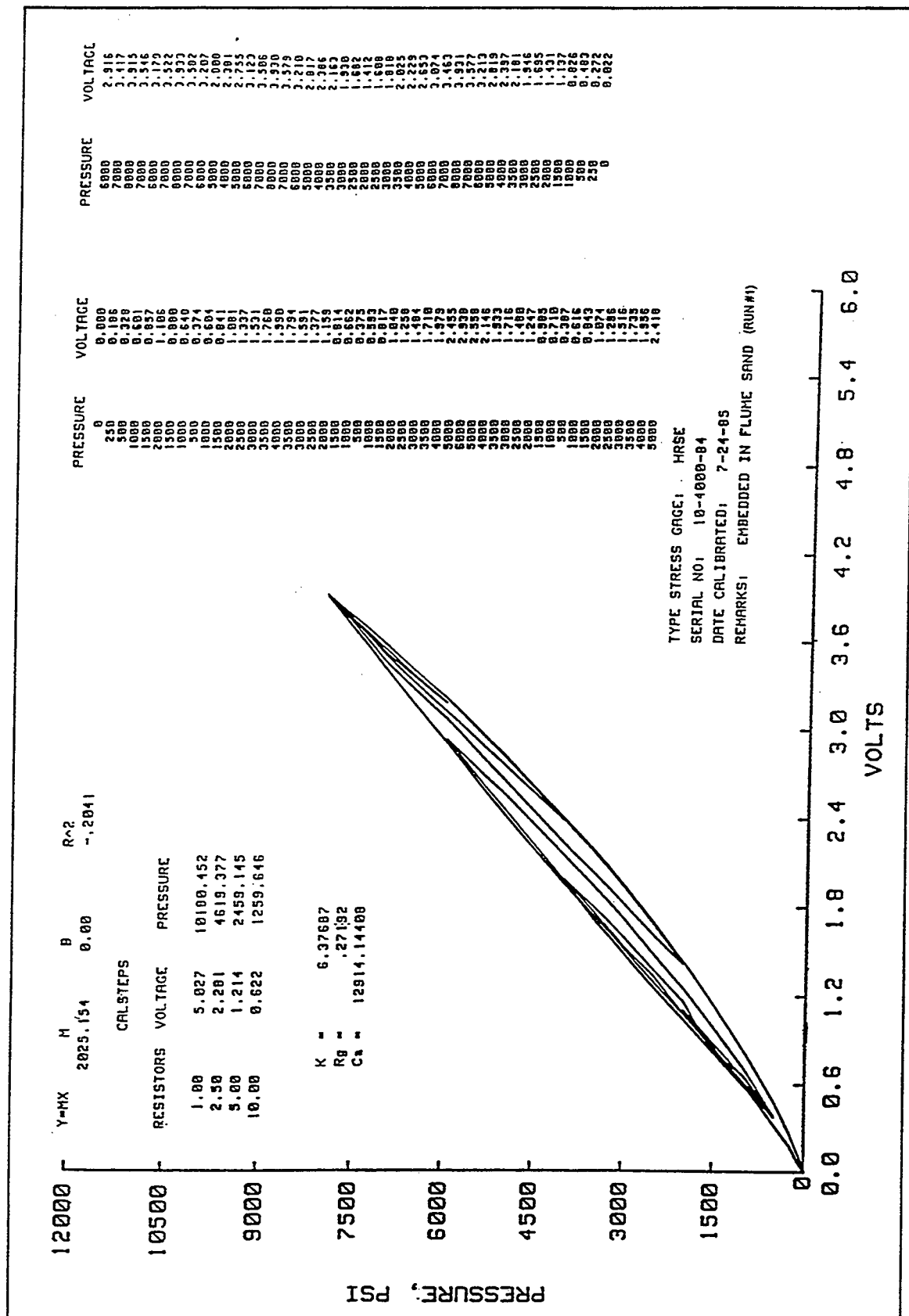


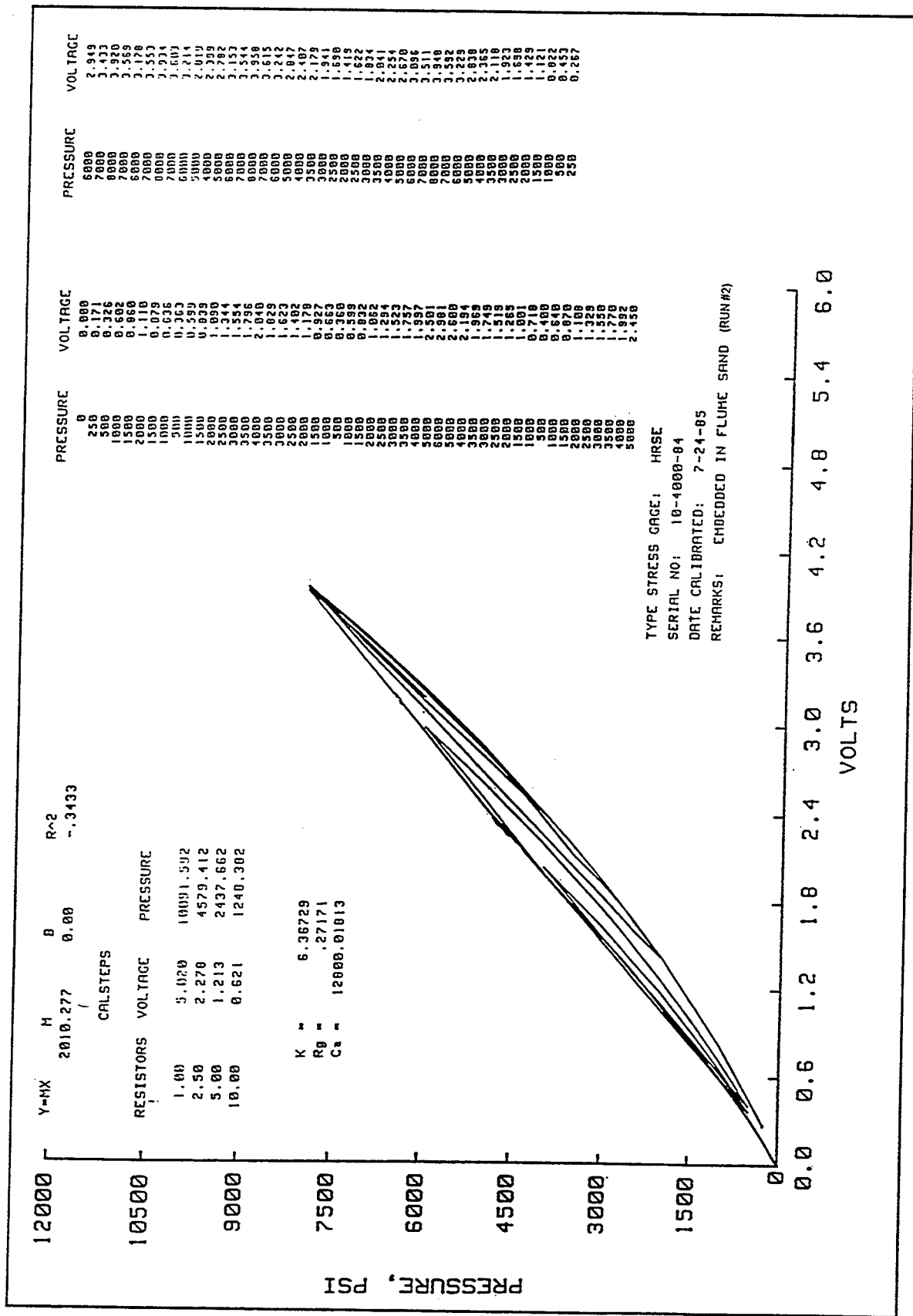


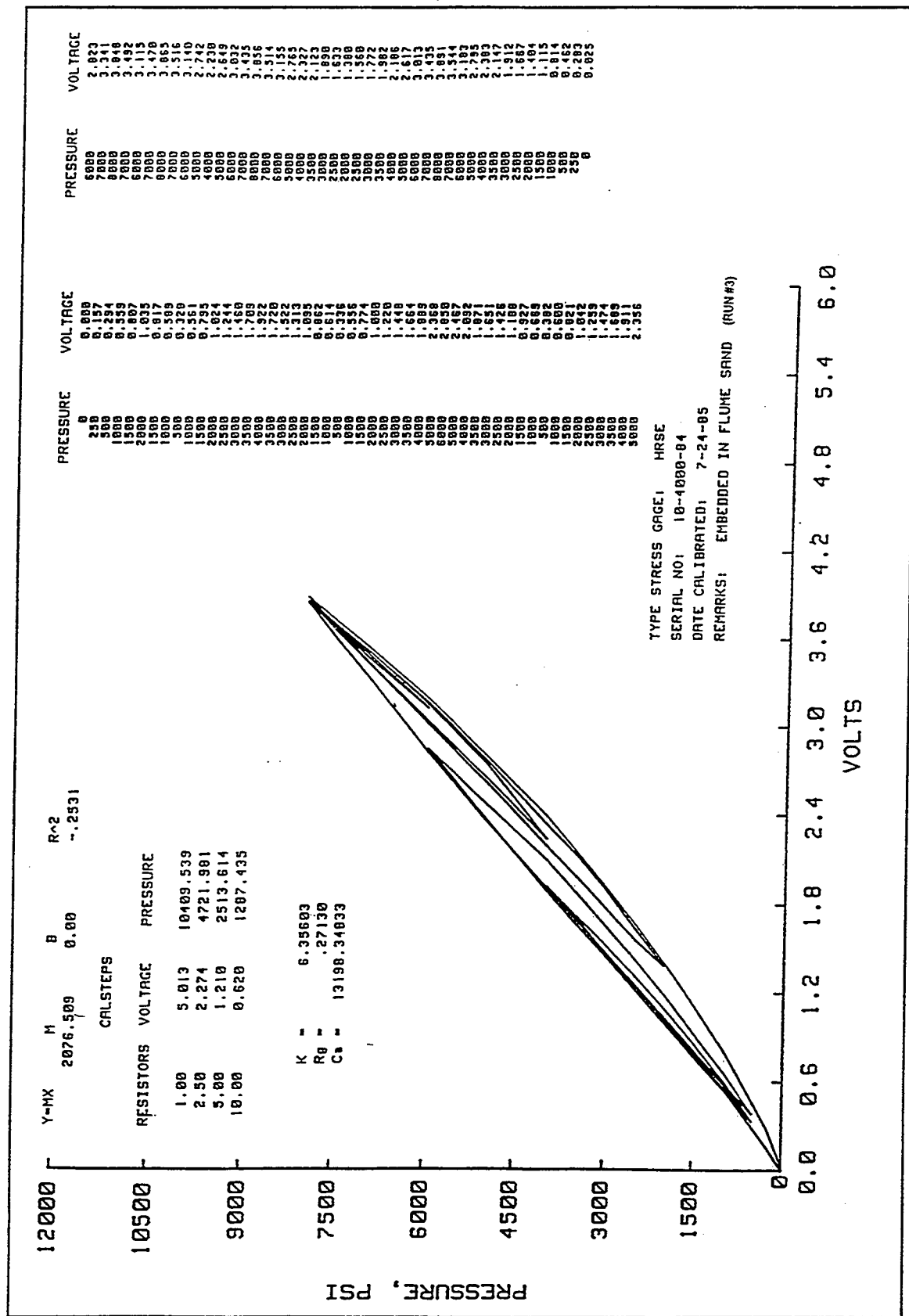


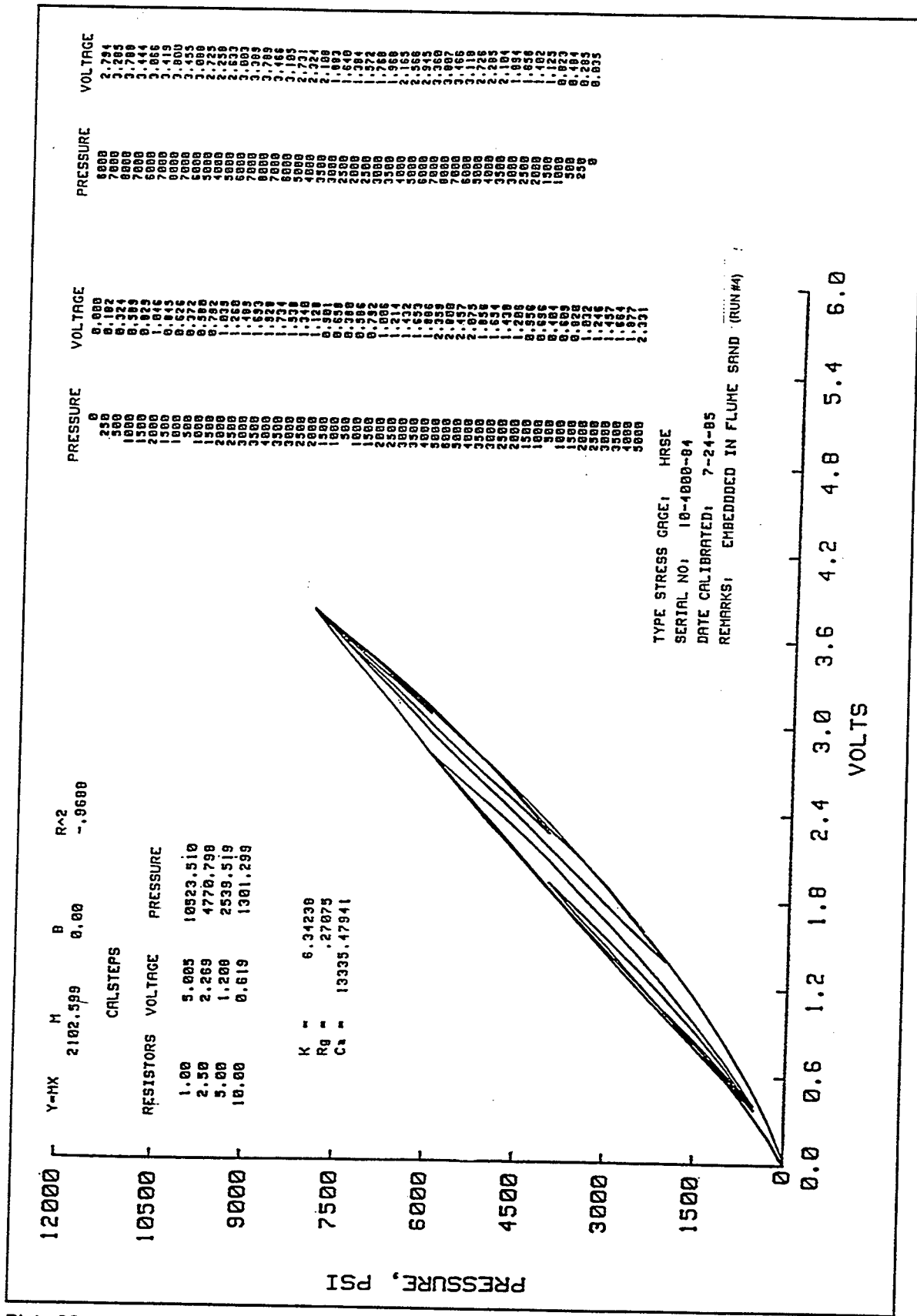


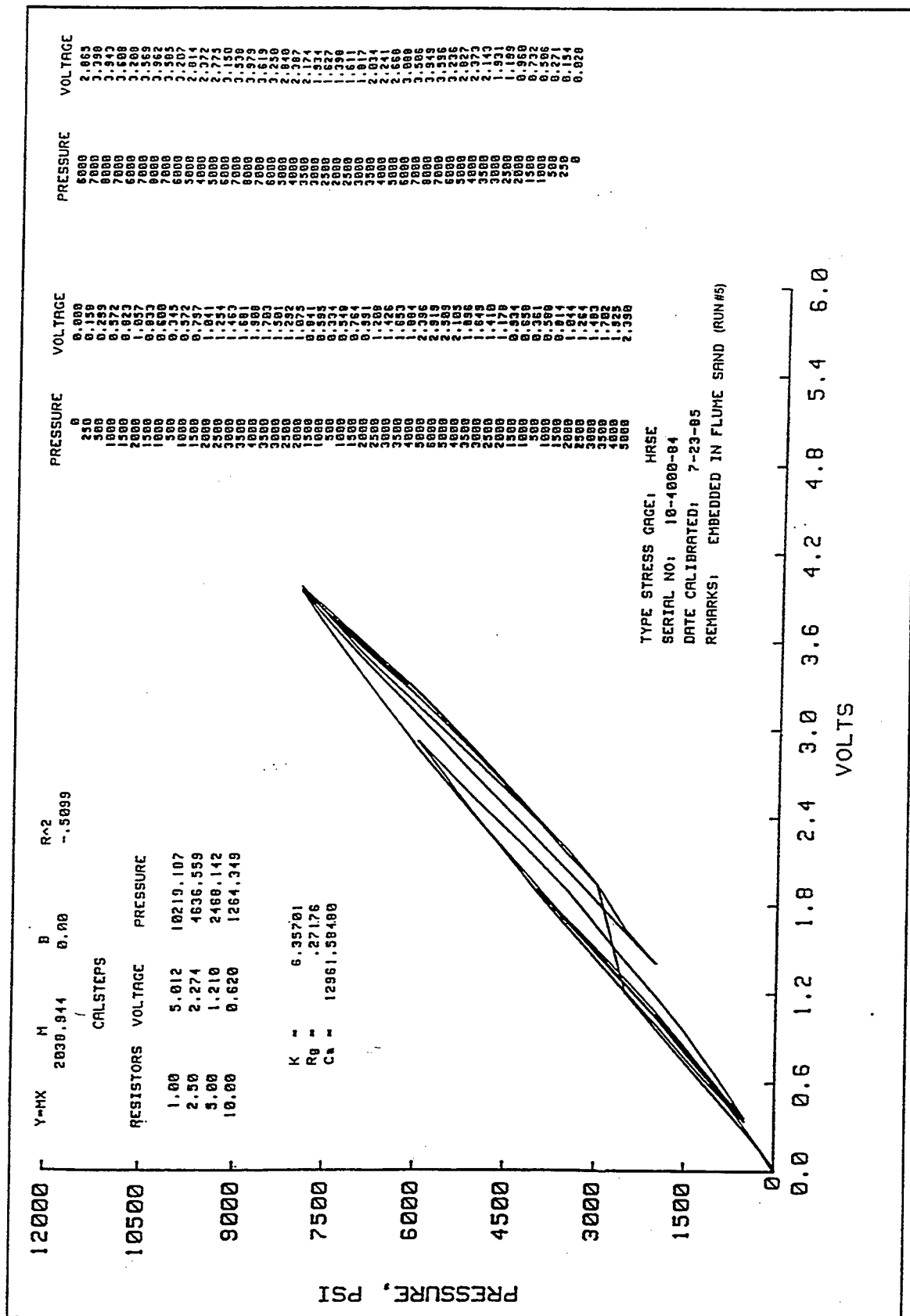


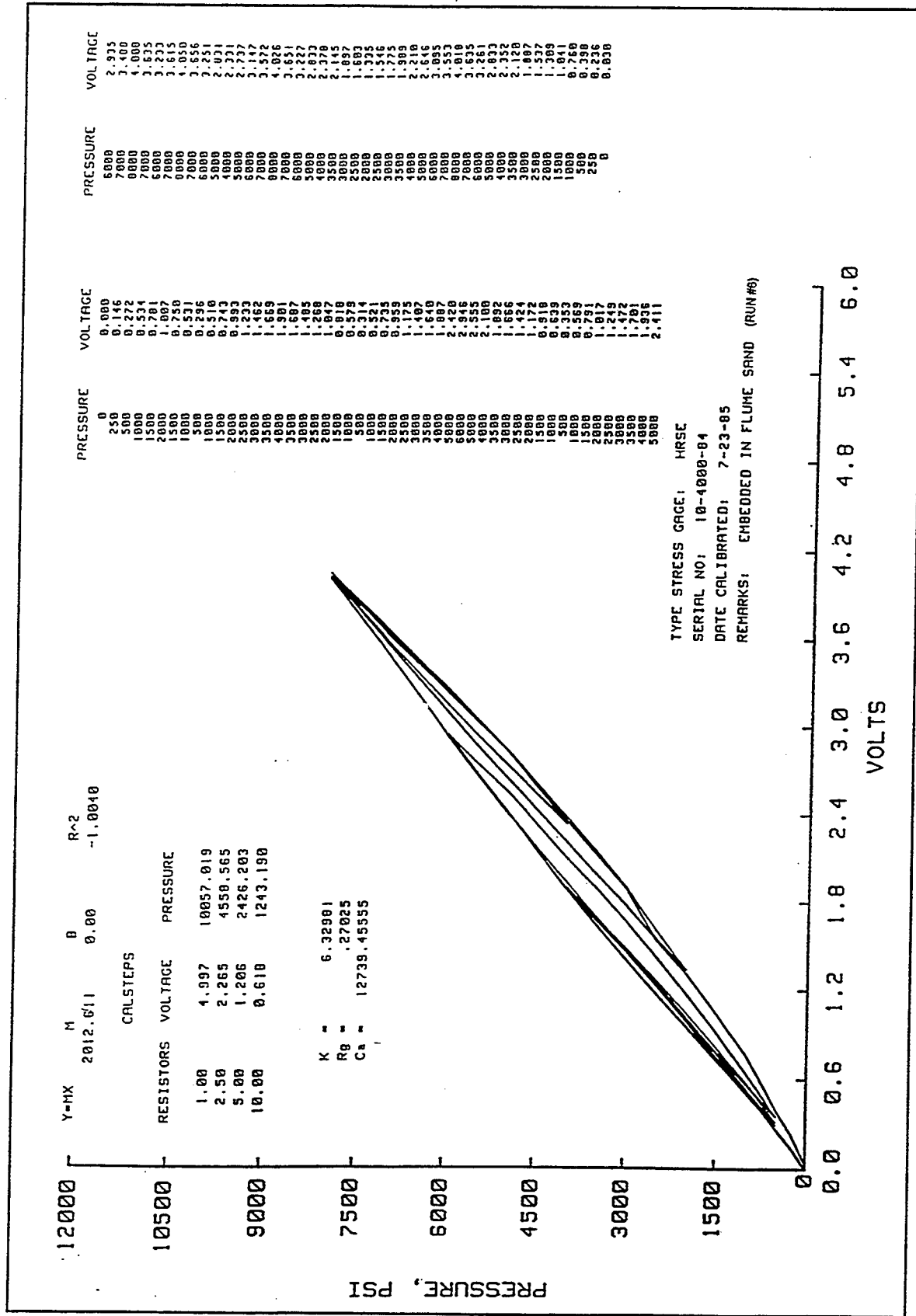


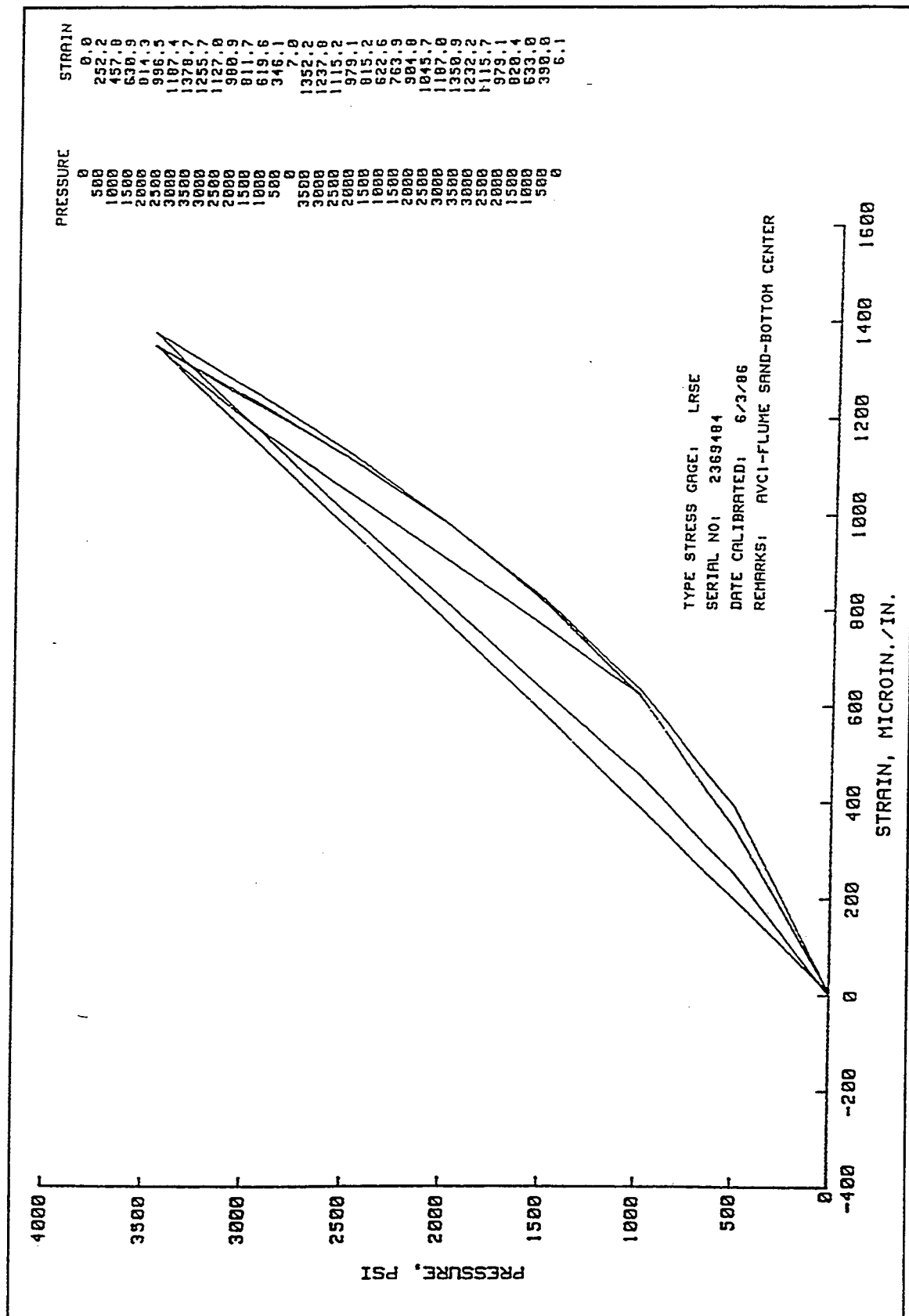




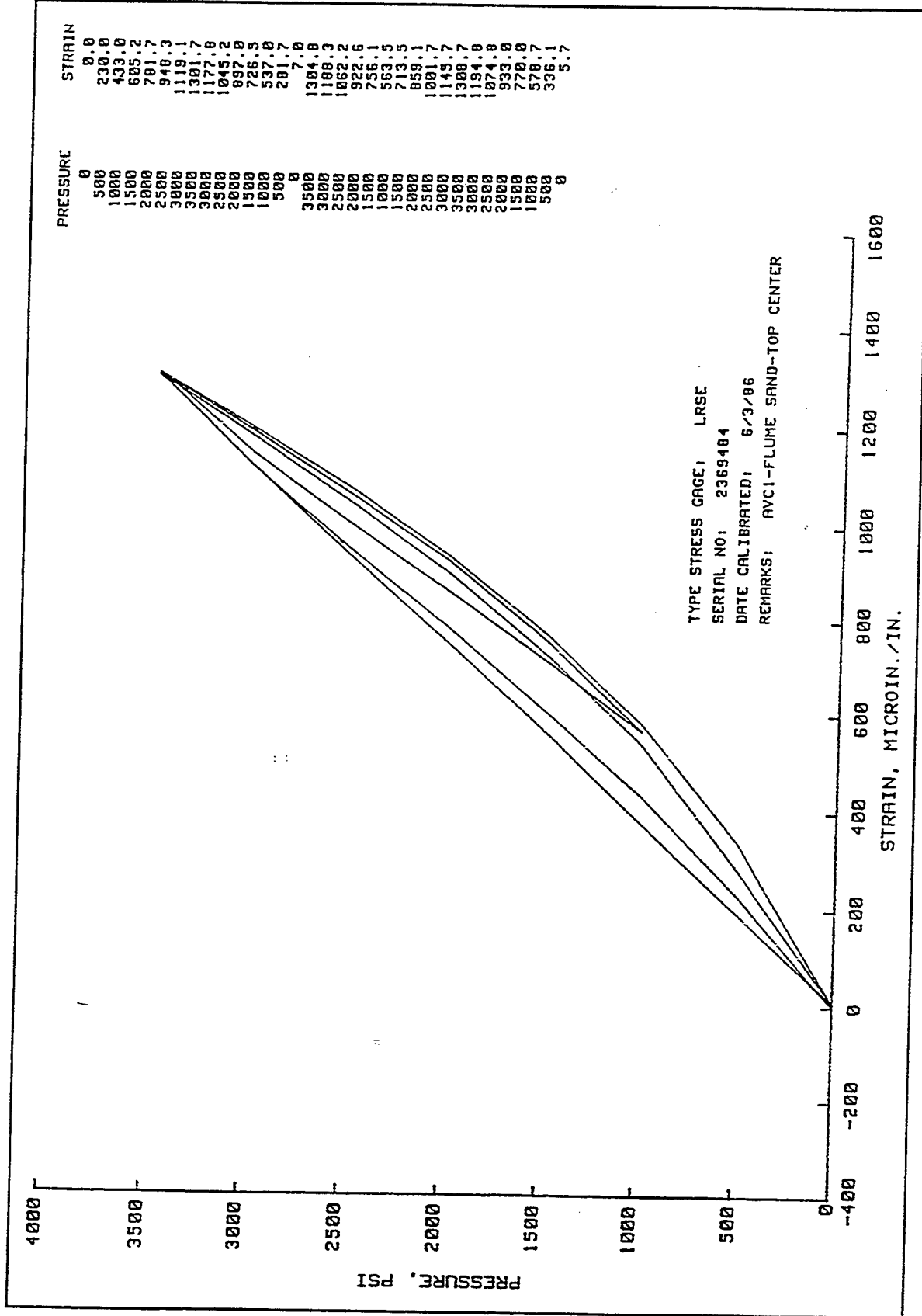


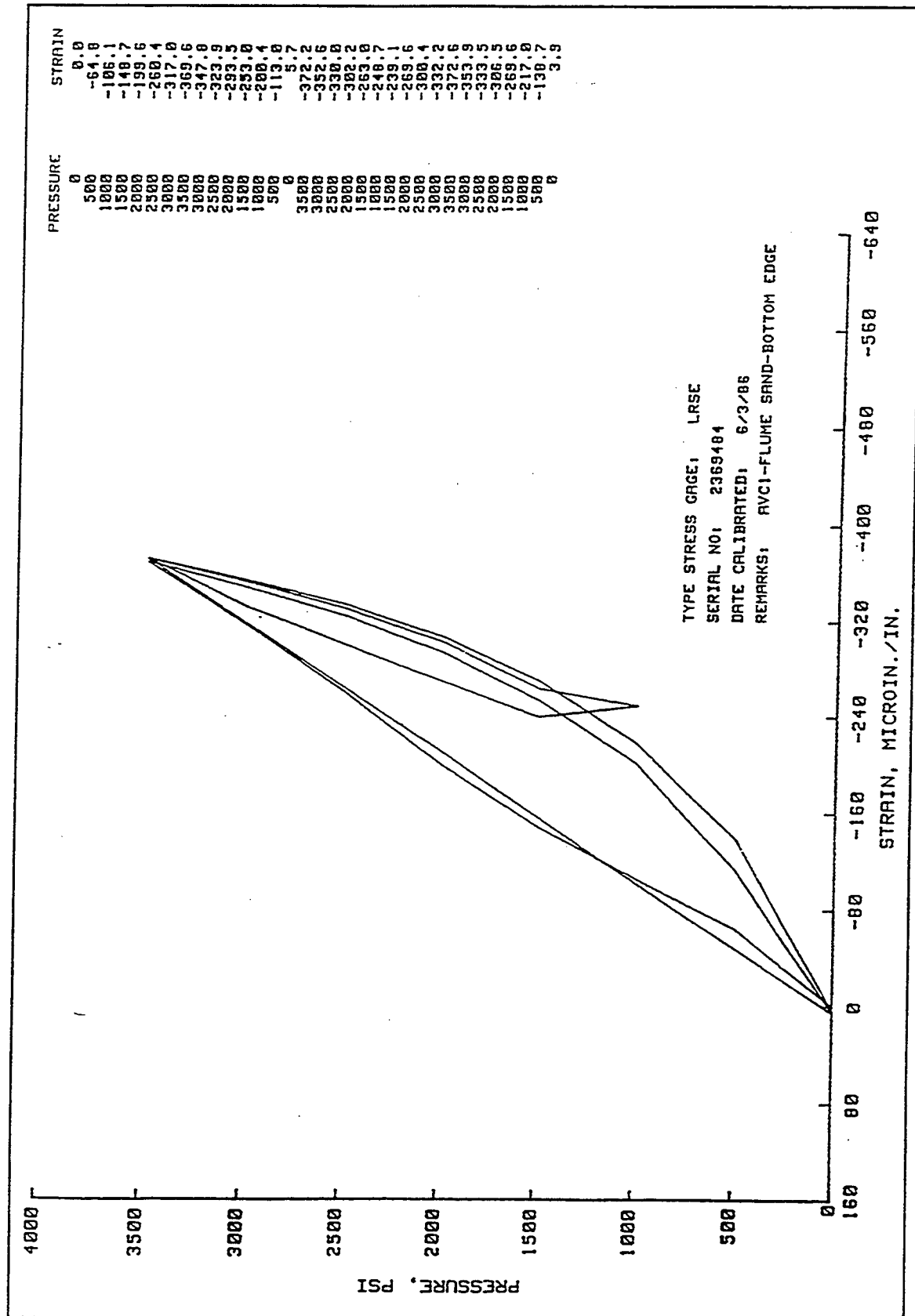


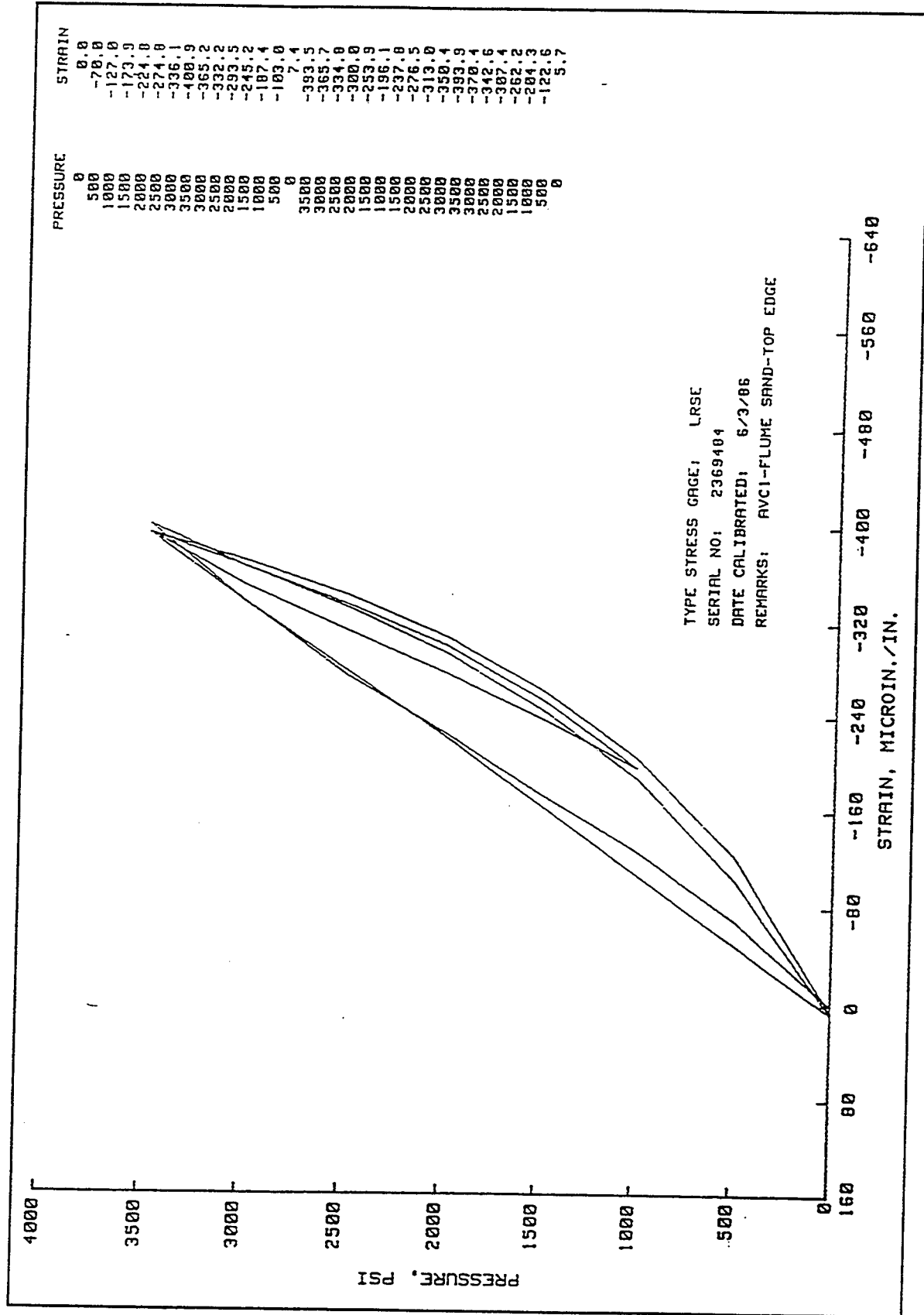


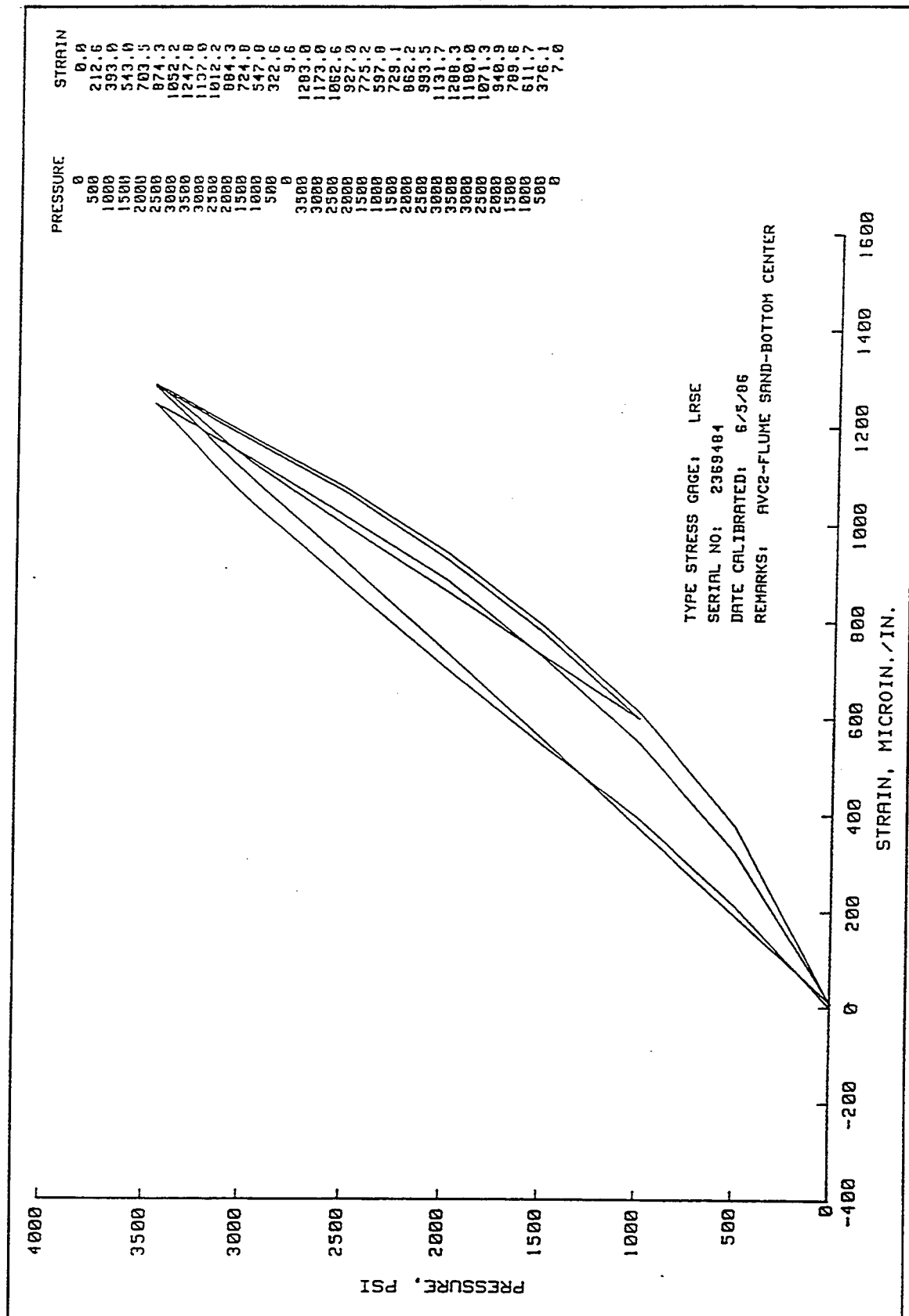


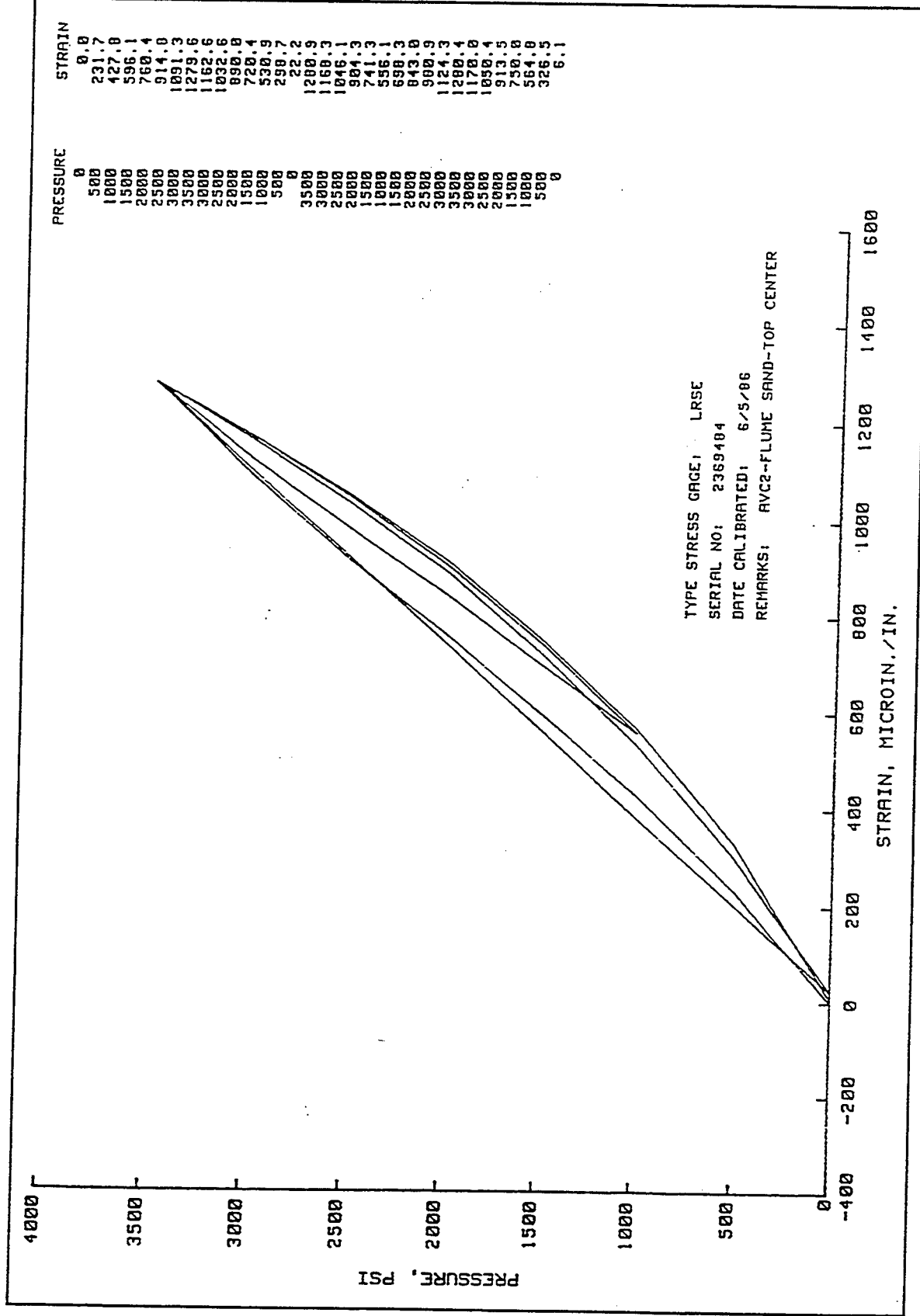


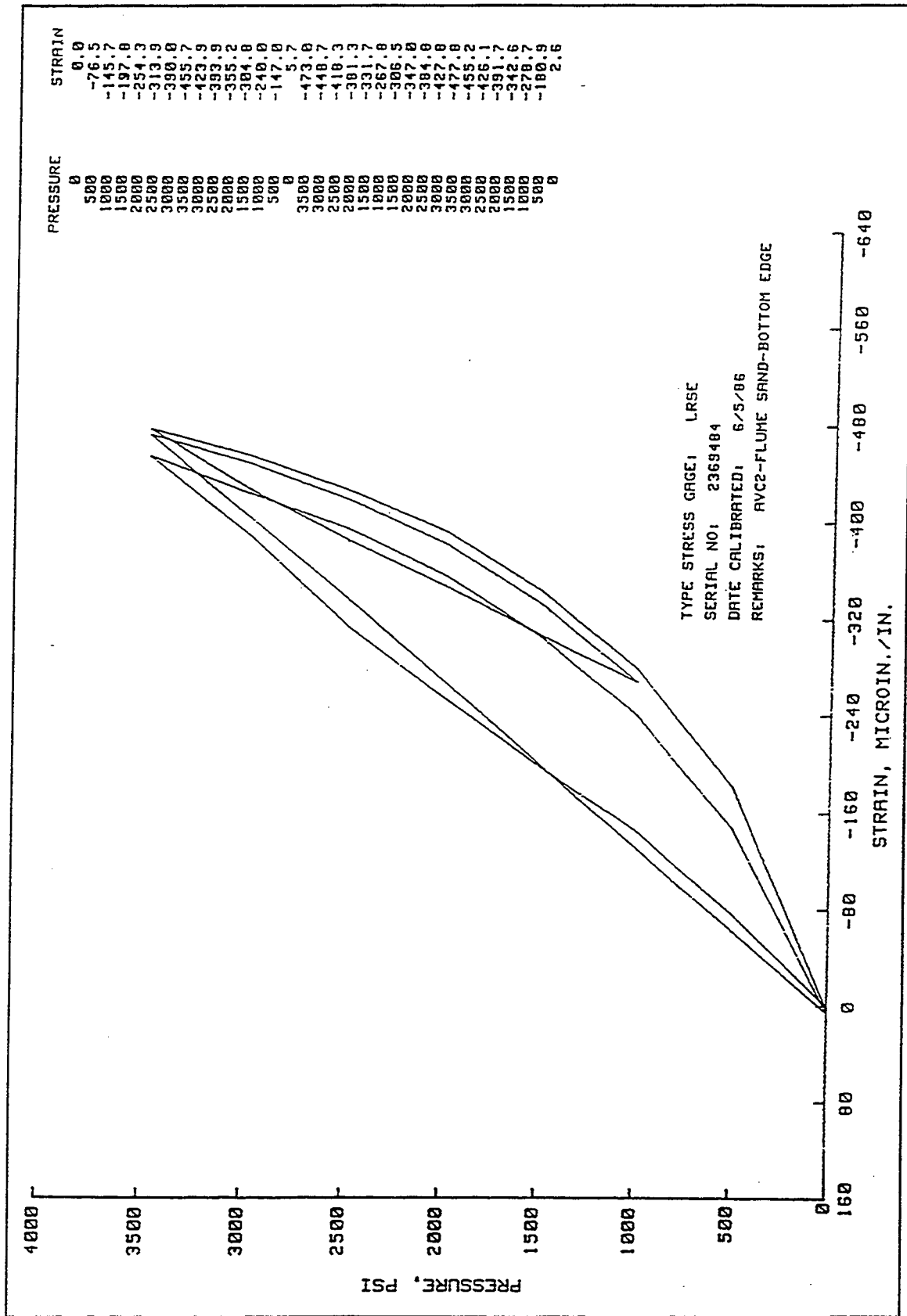


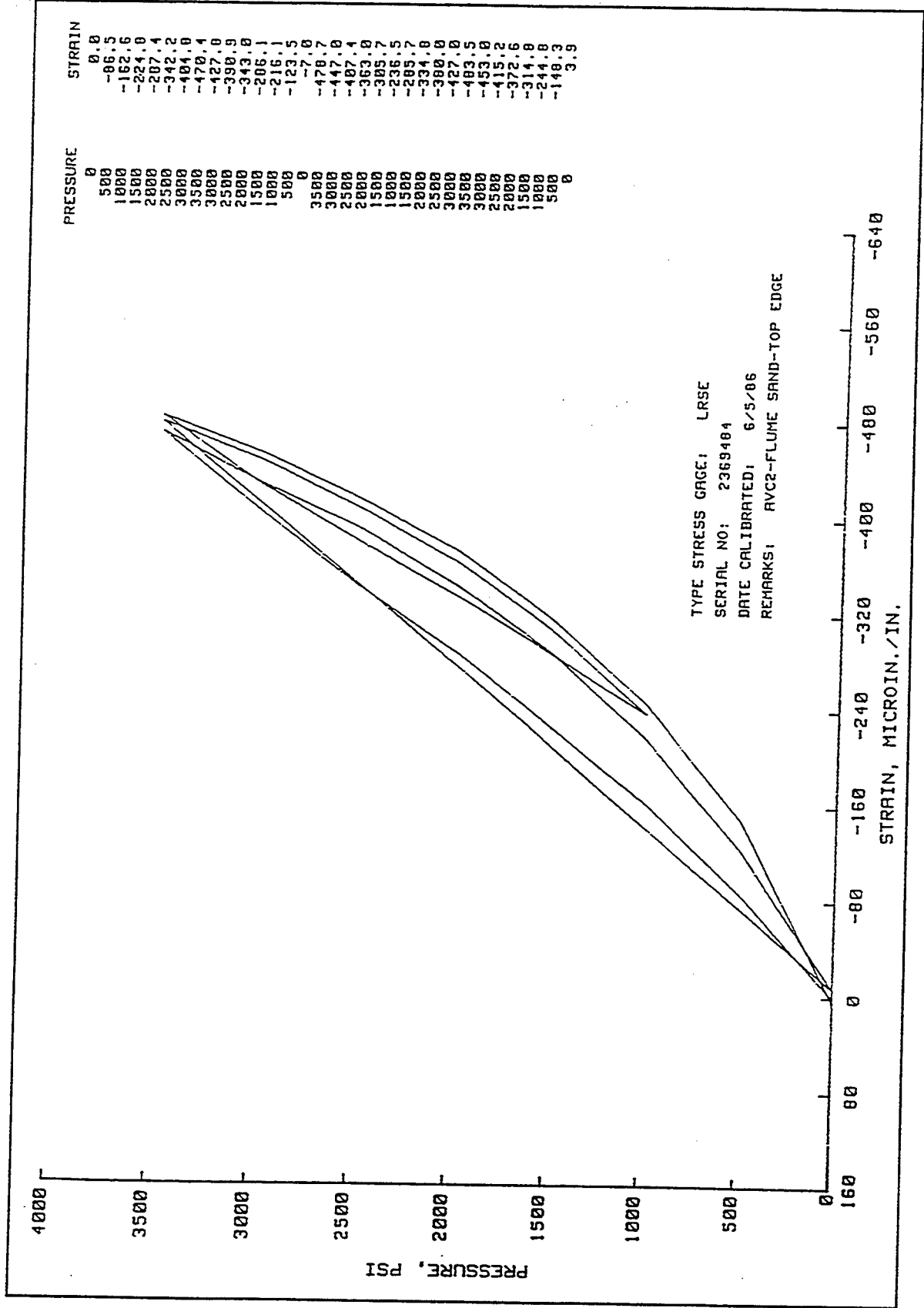


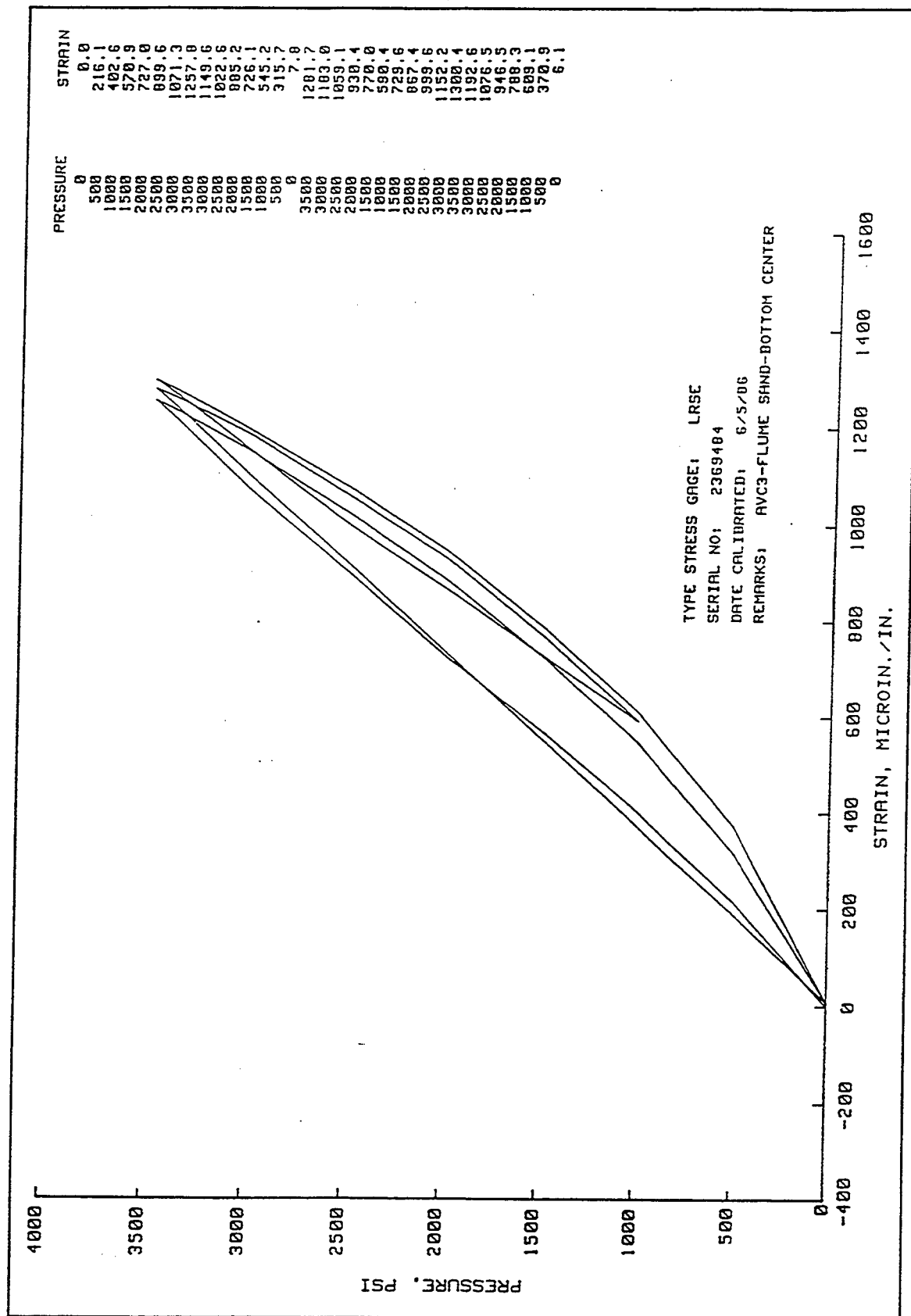




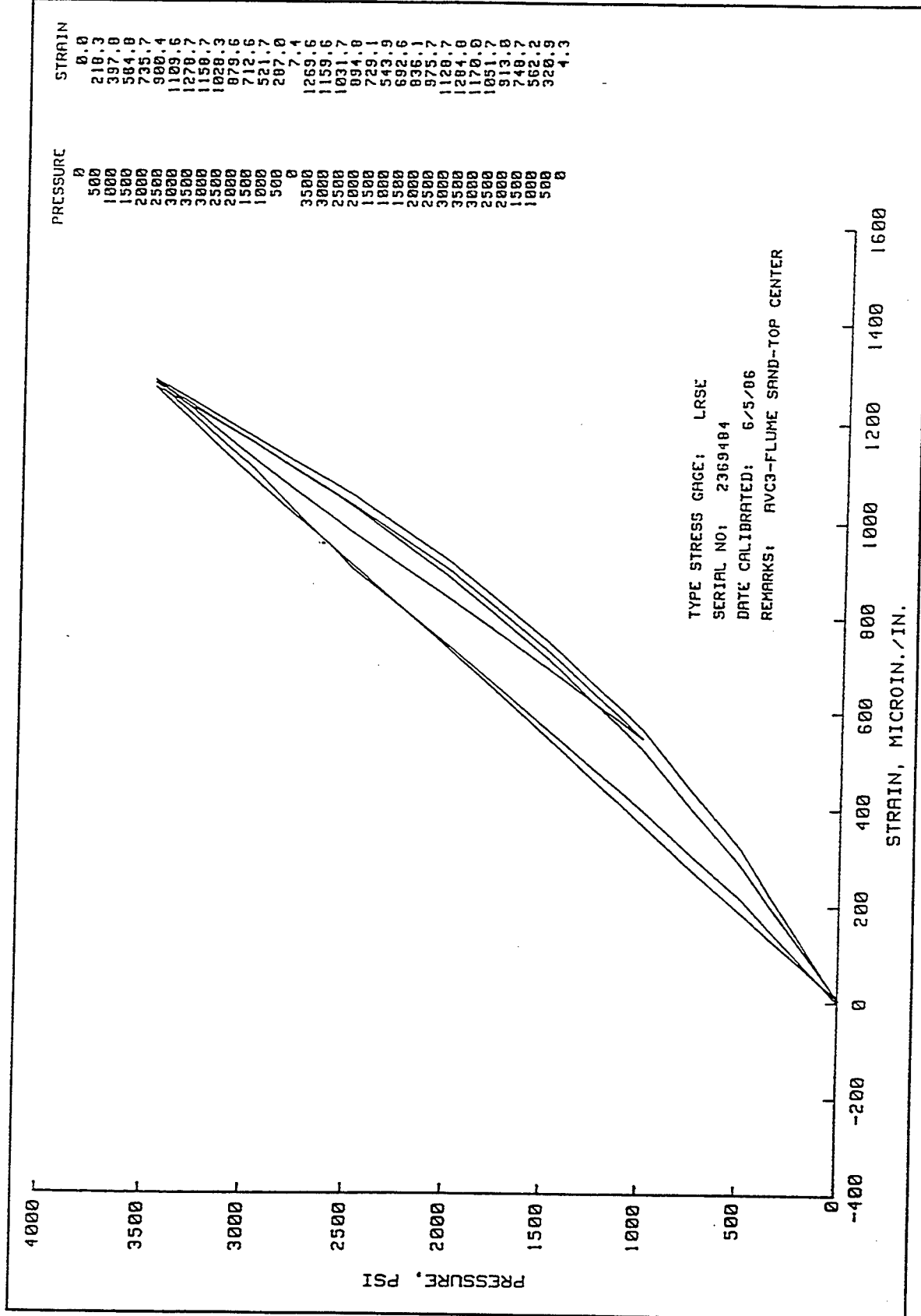


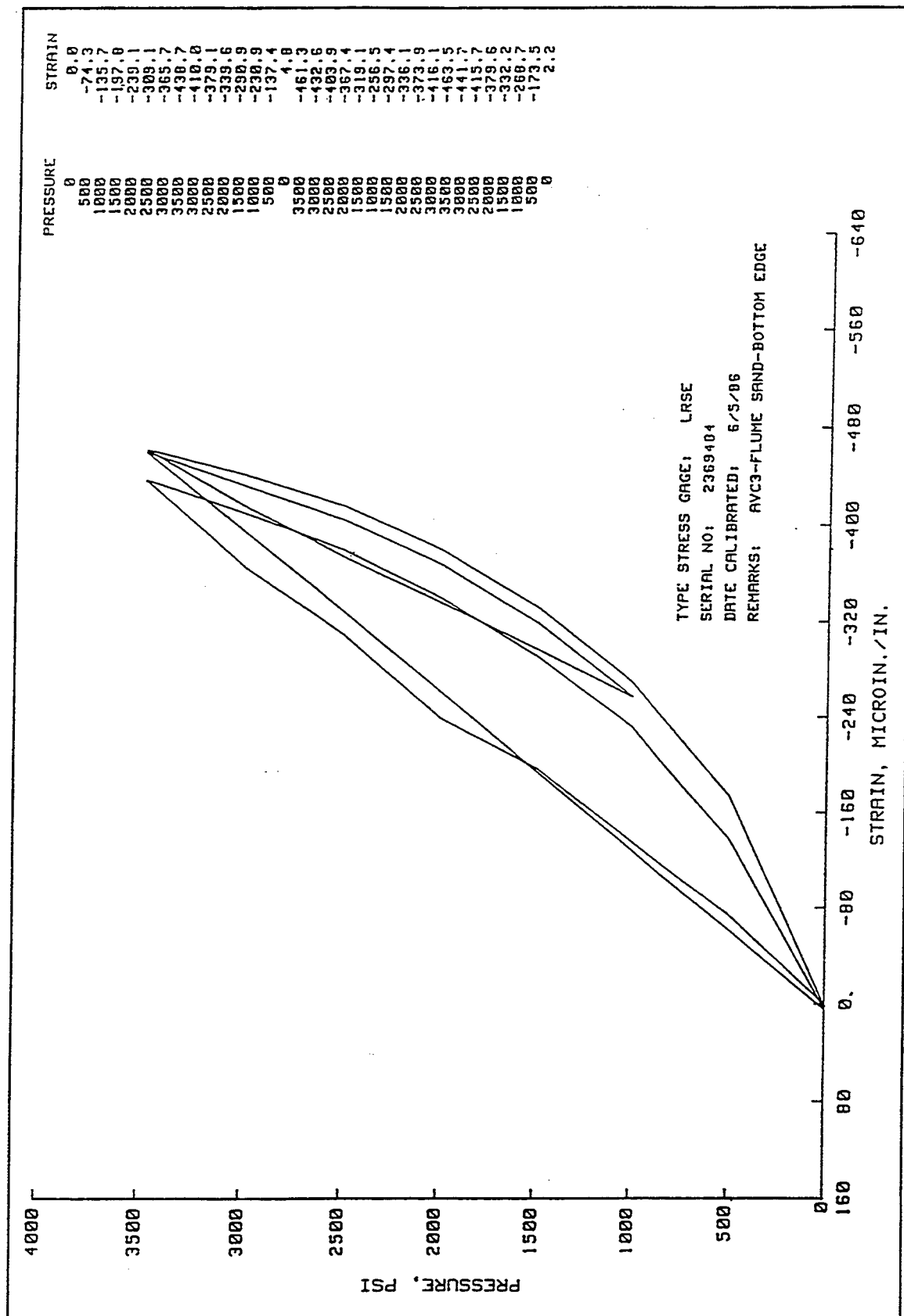


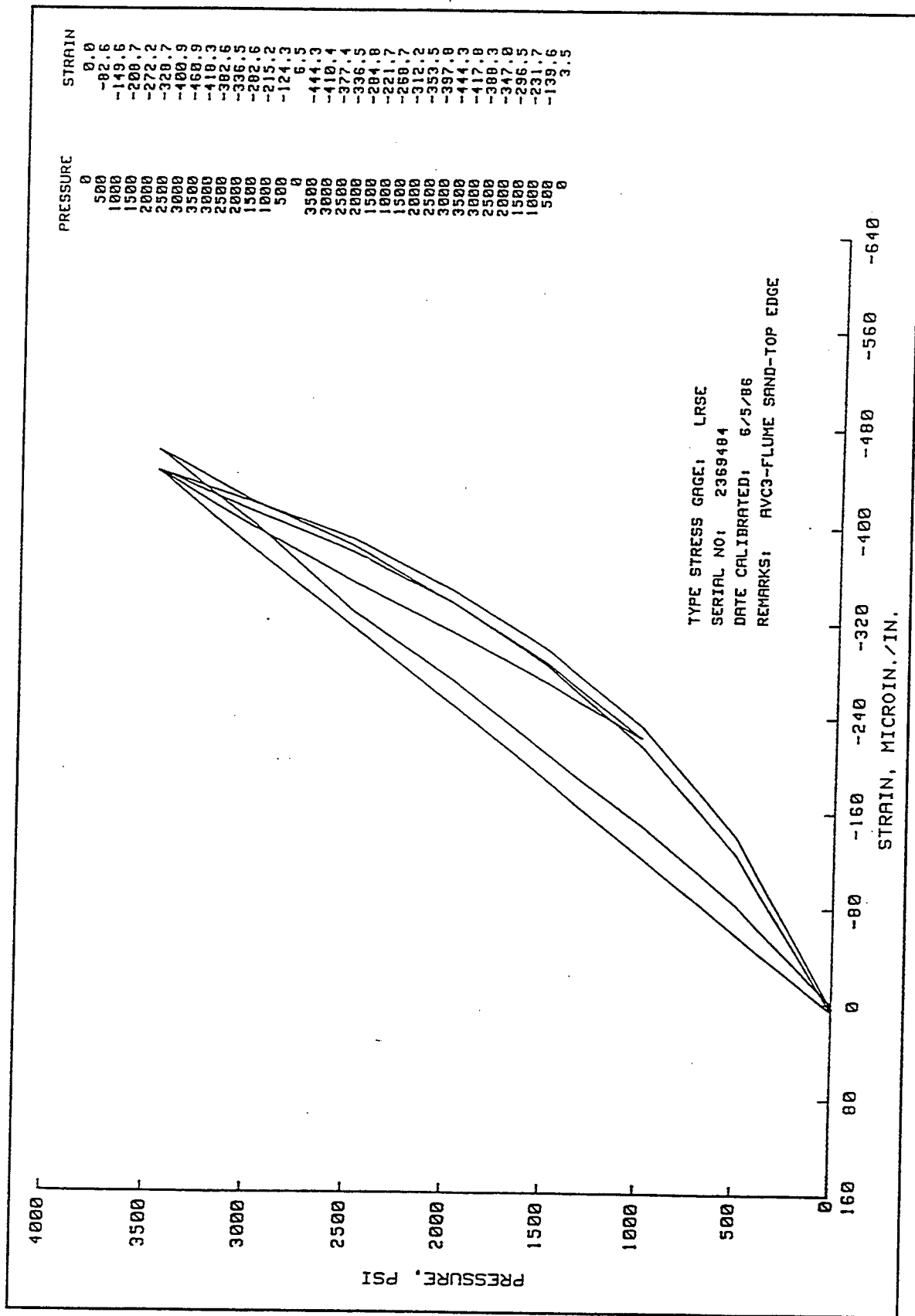


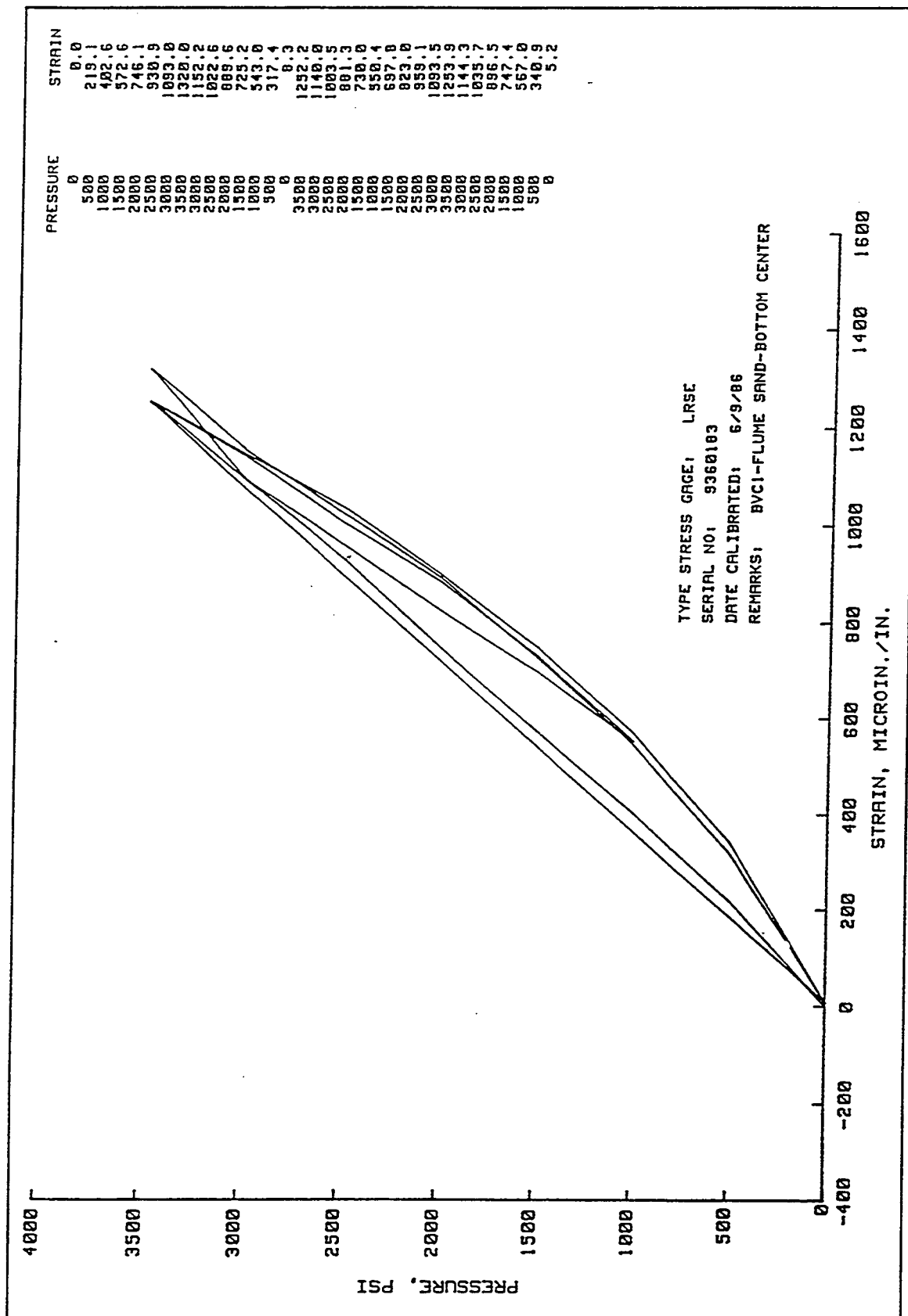


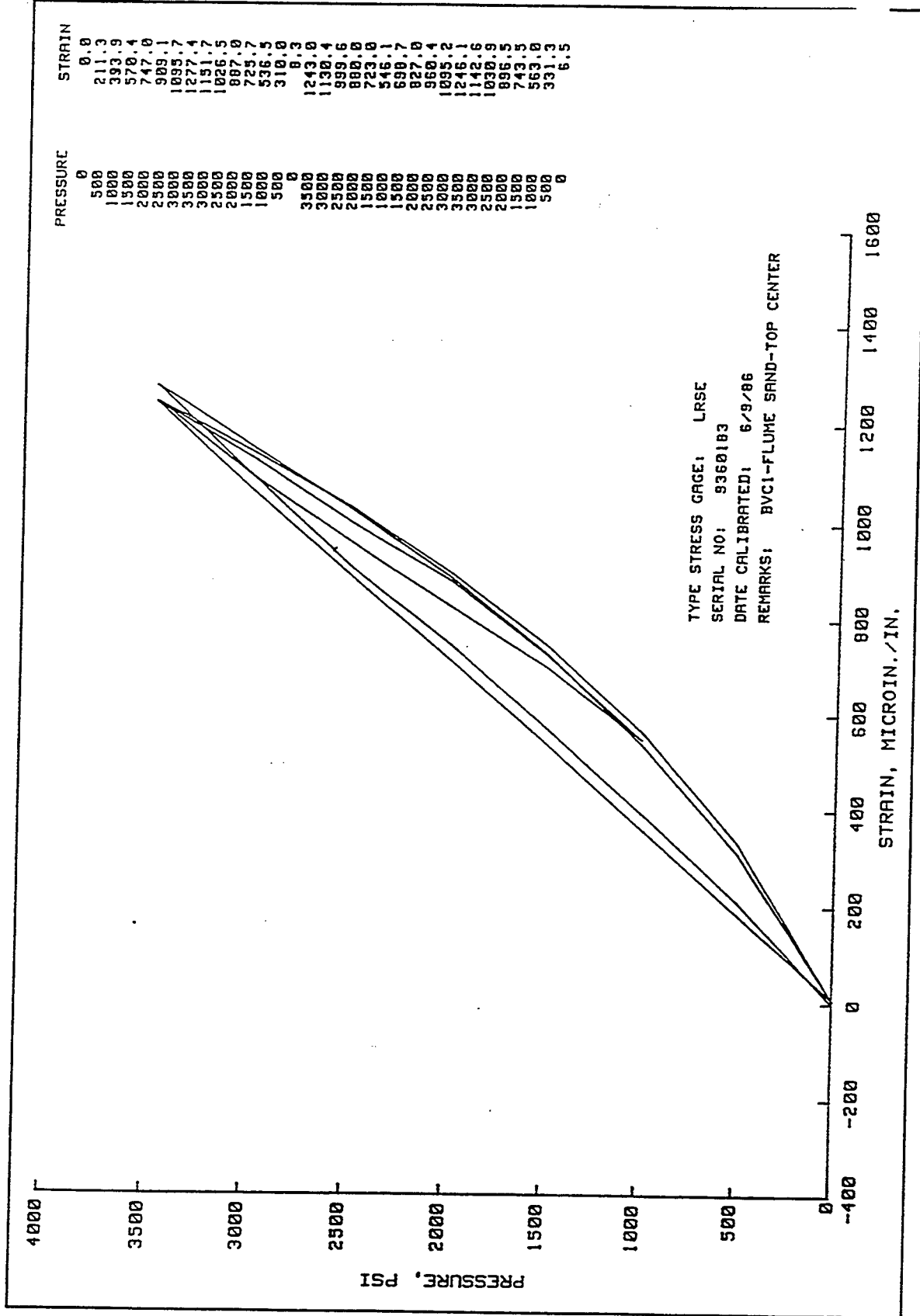


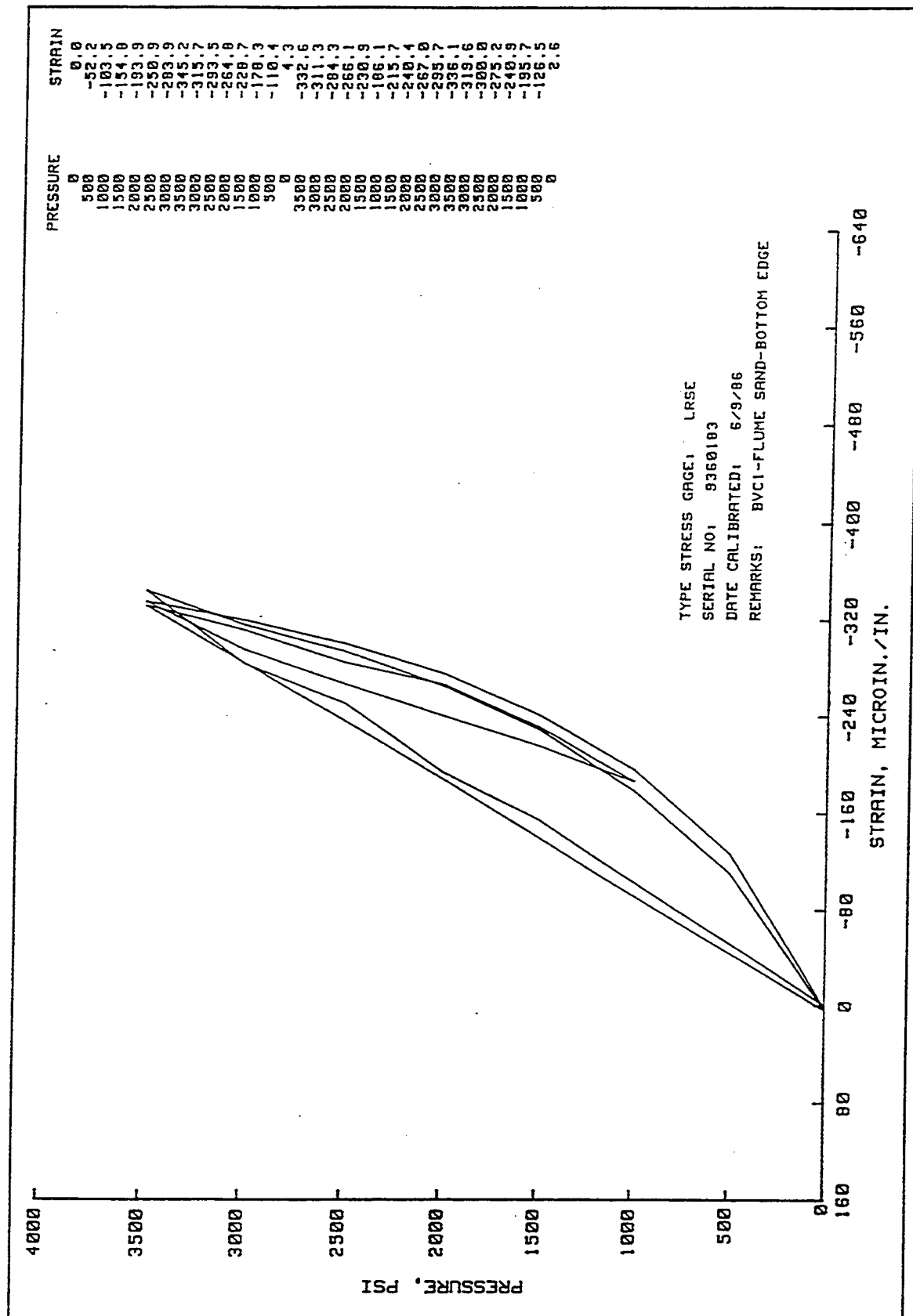


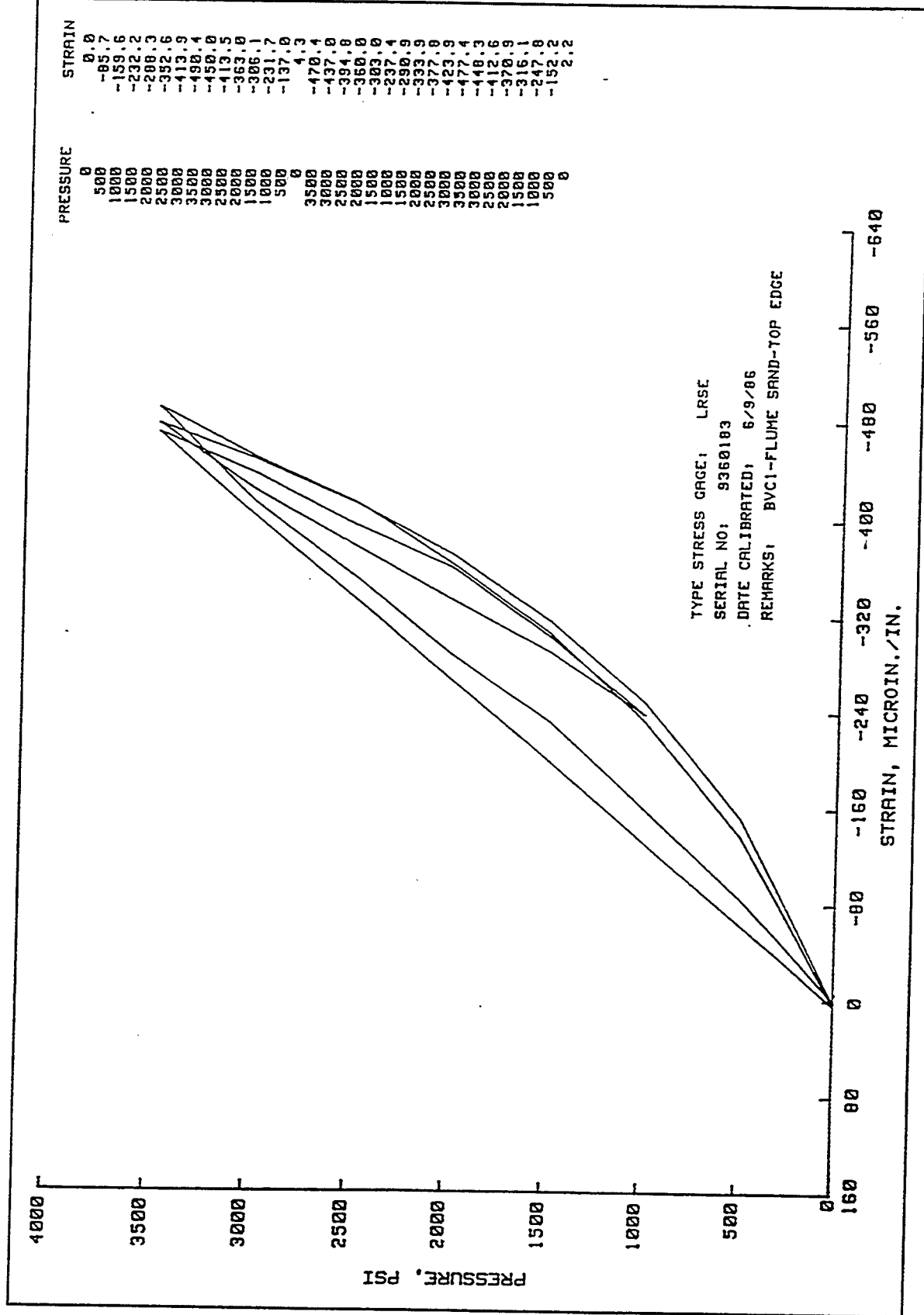


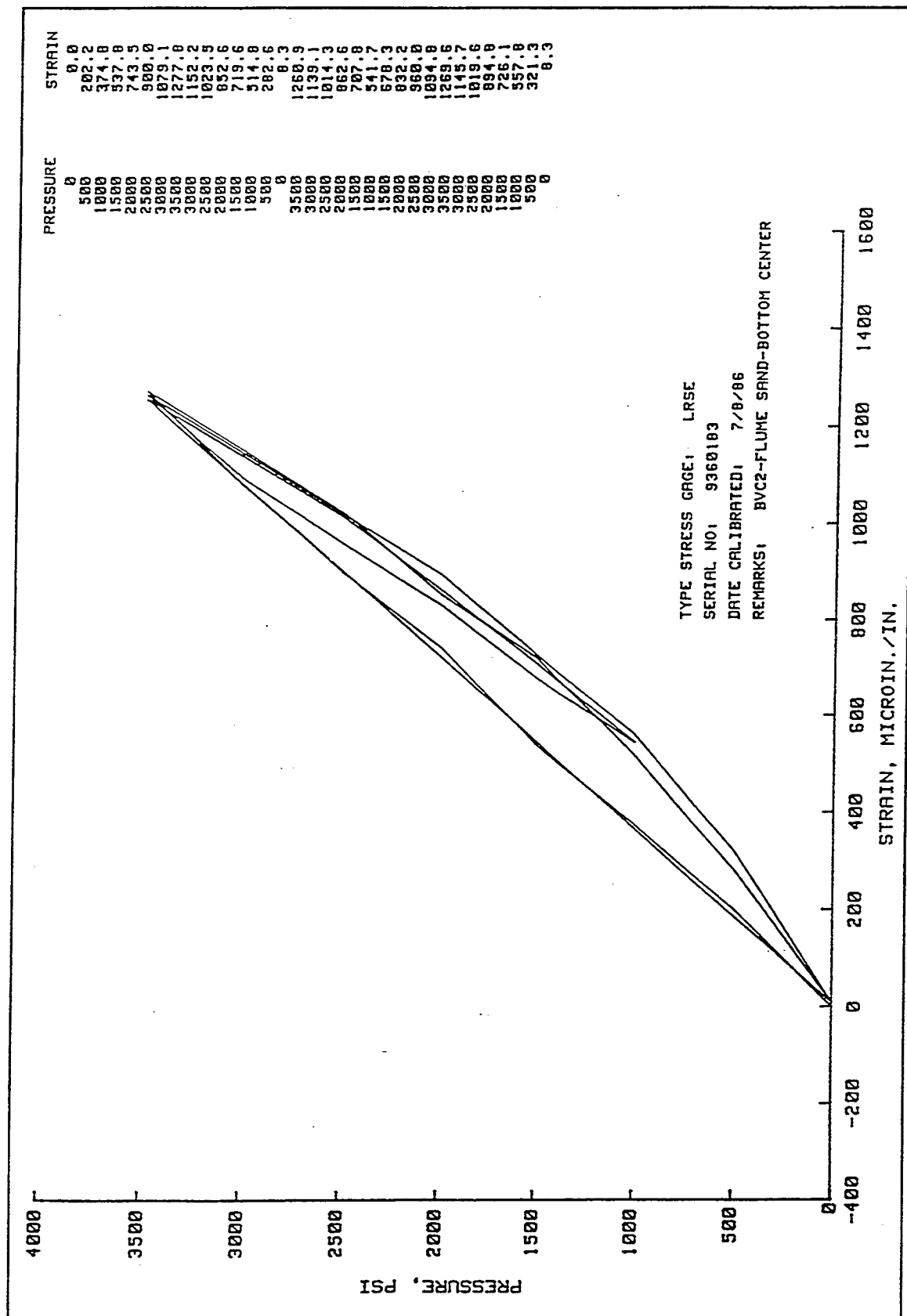














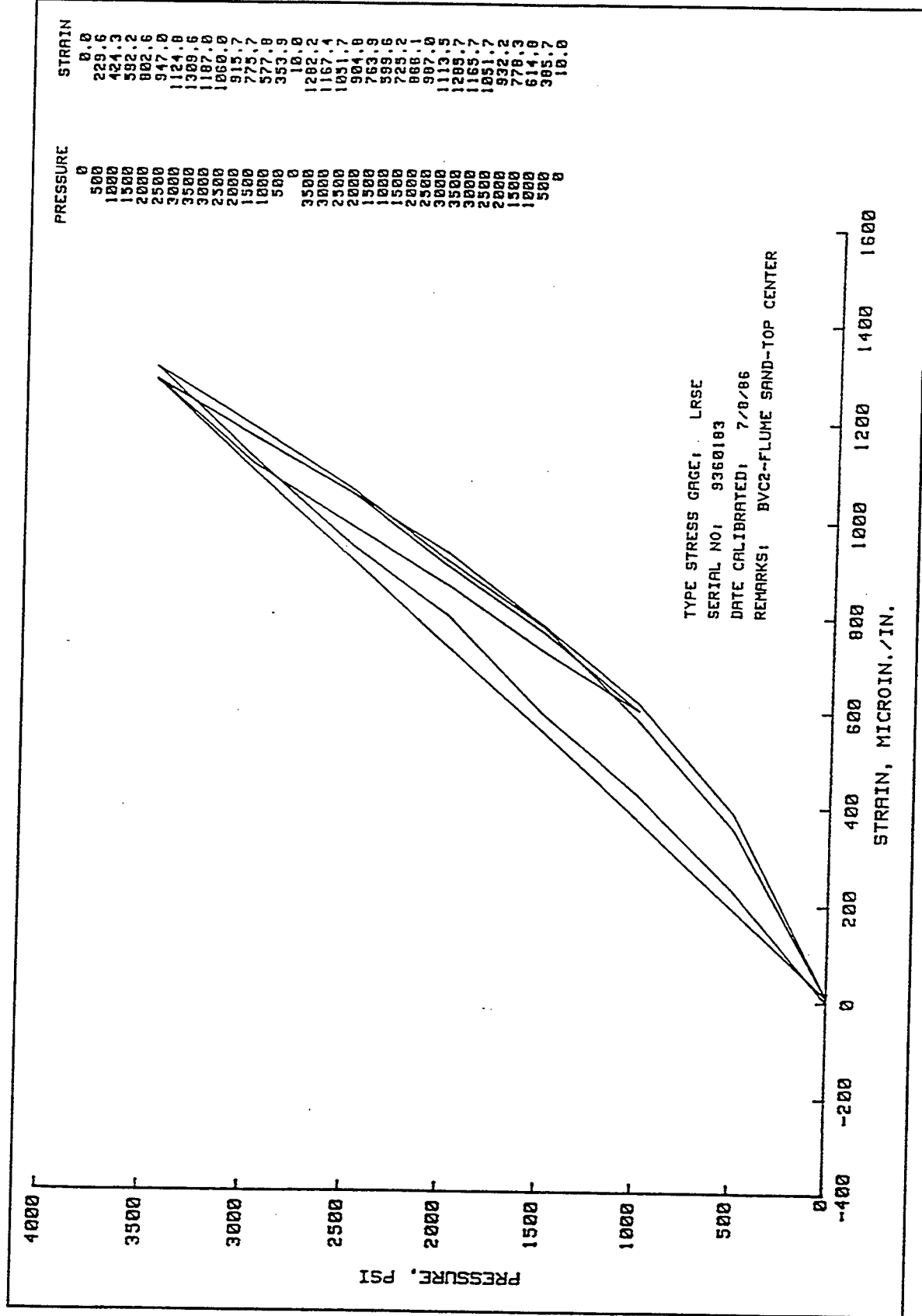
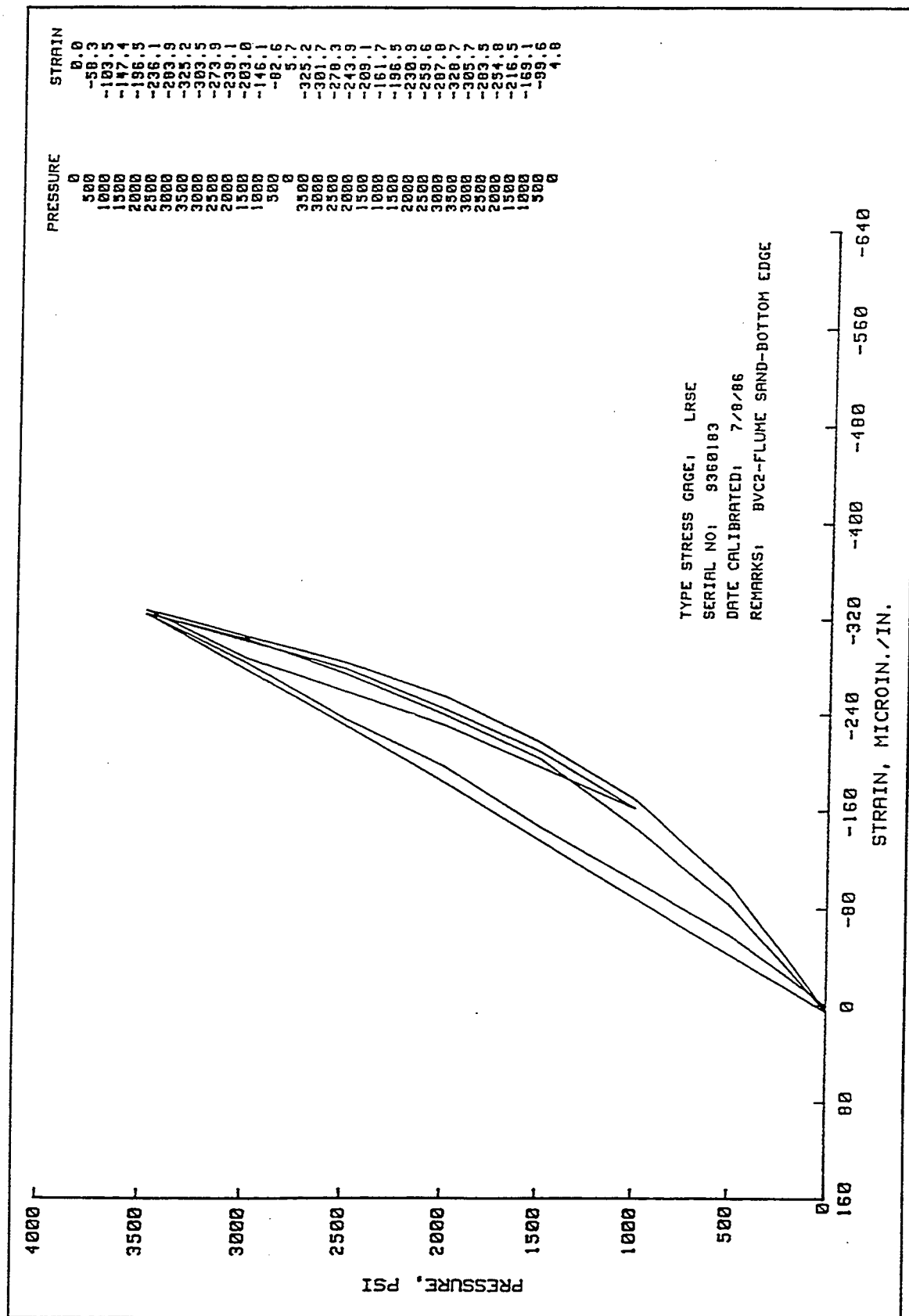
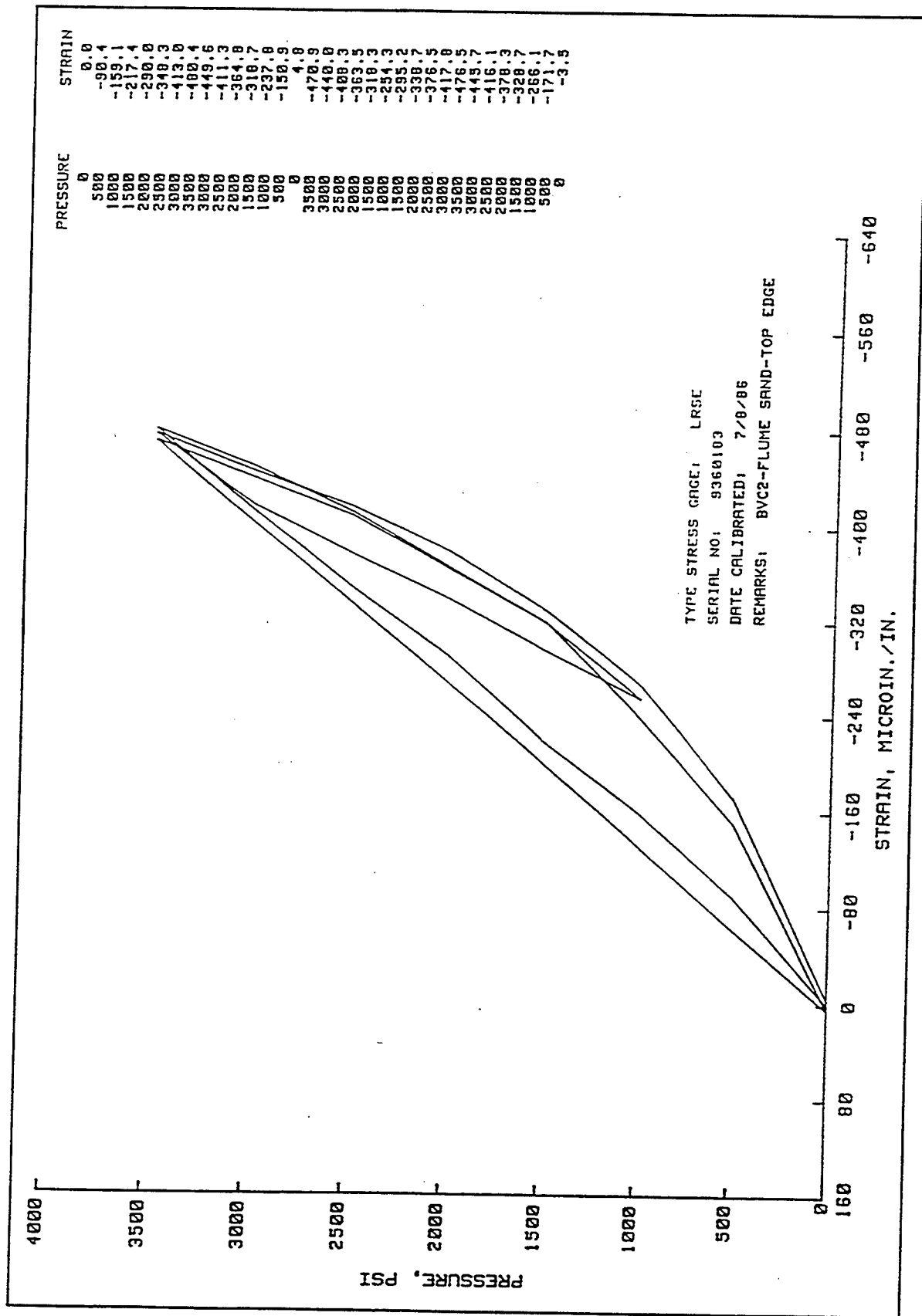
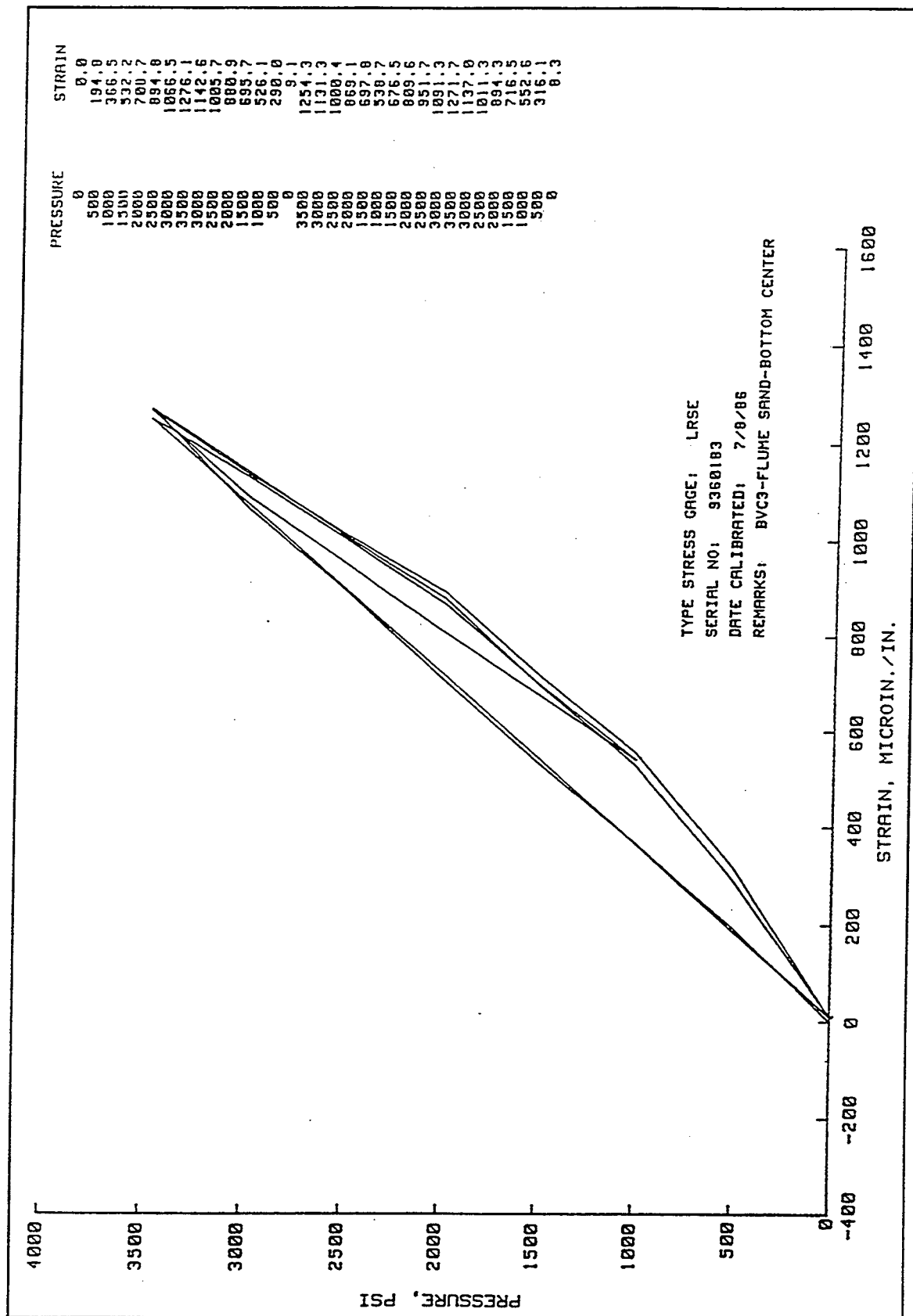


Plate 112







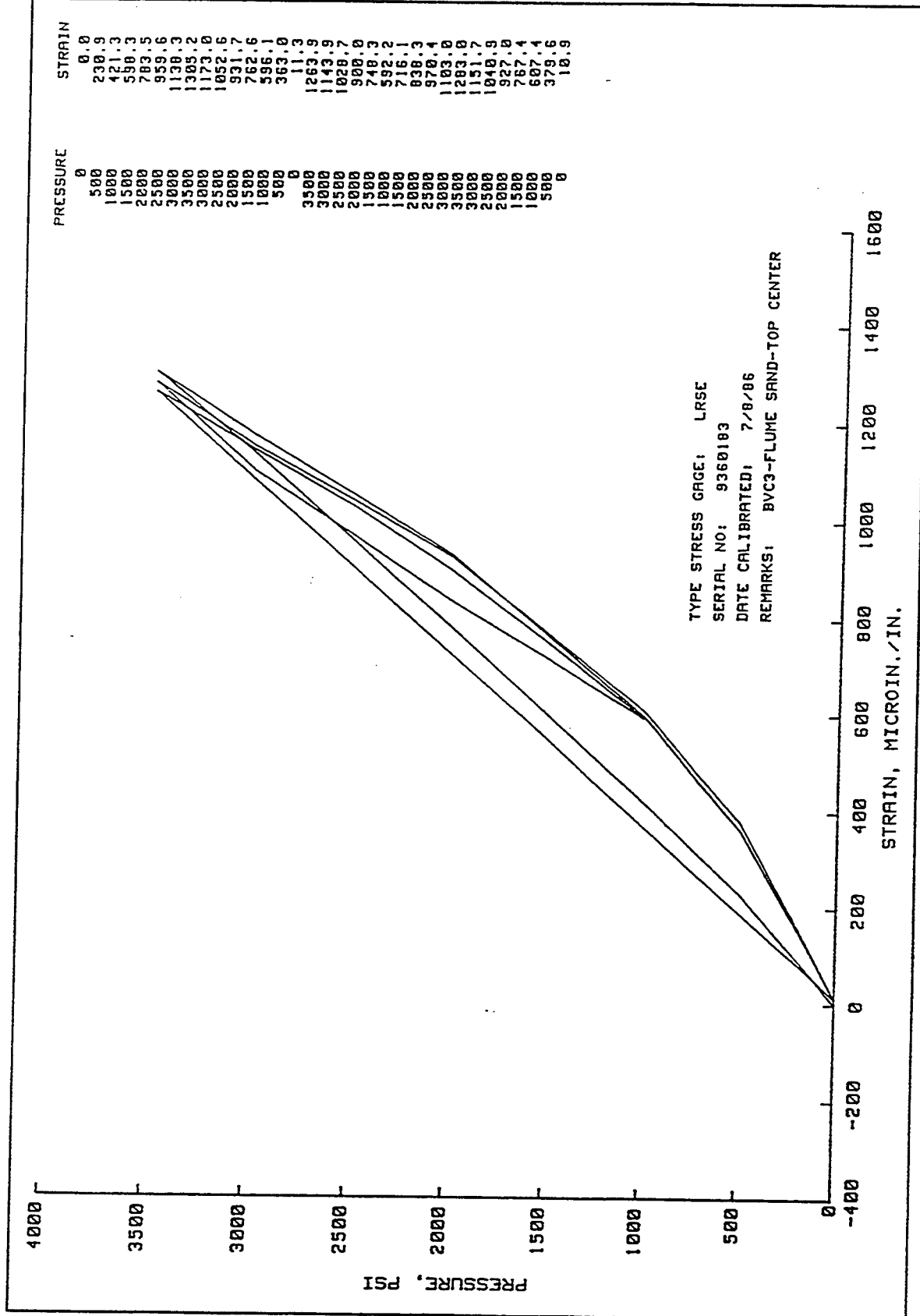
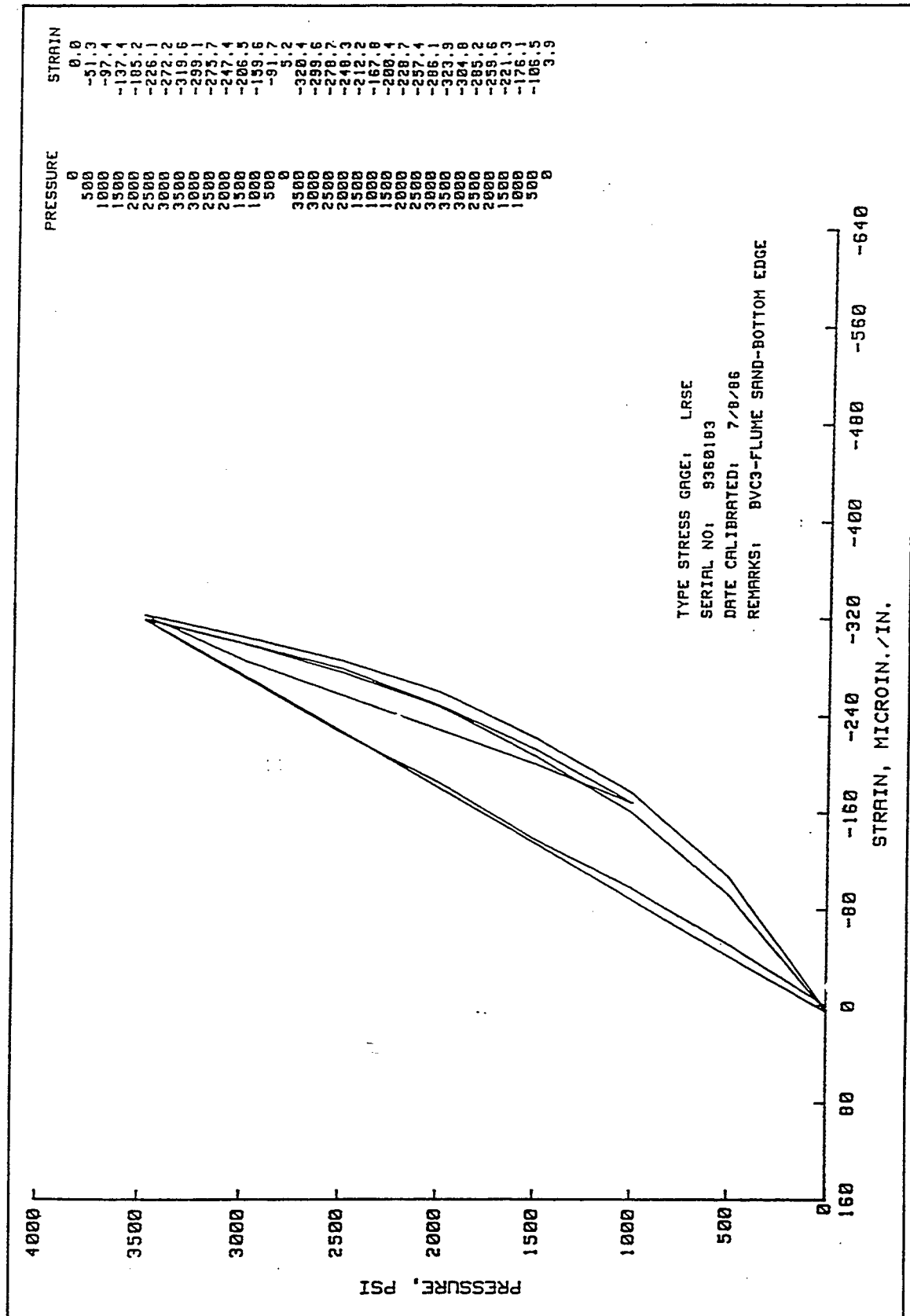
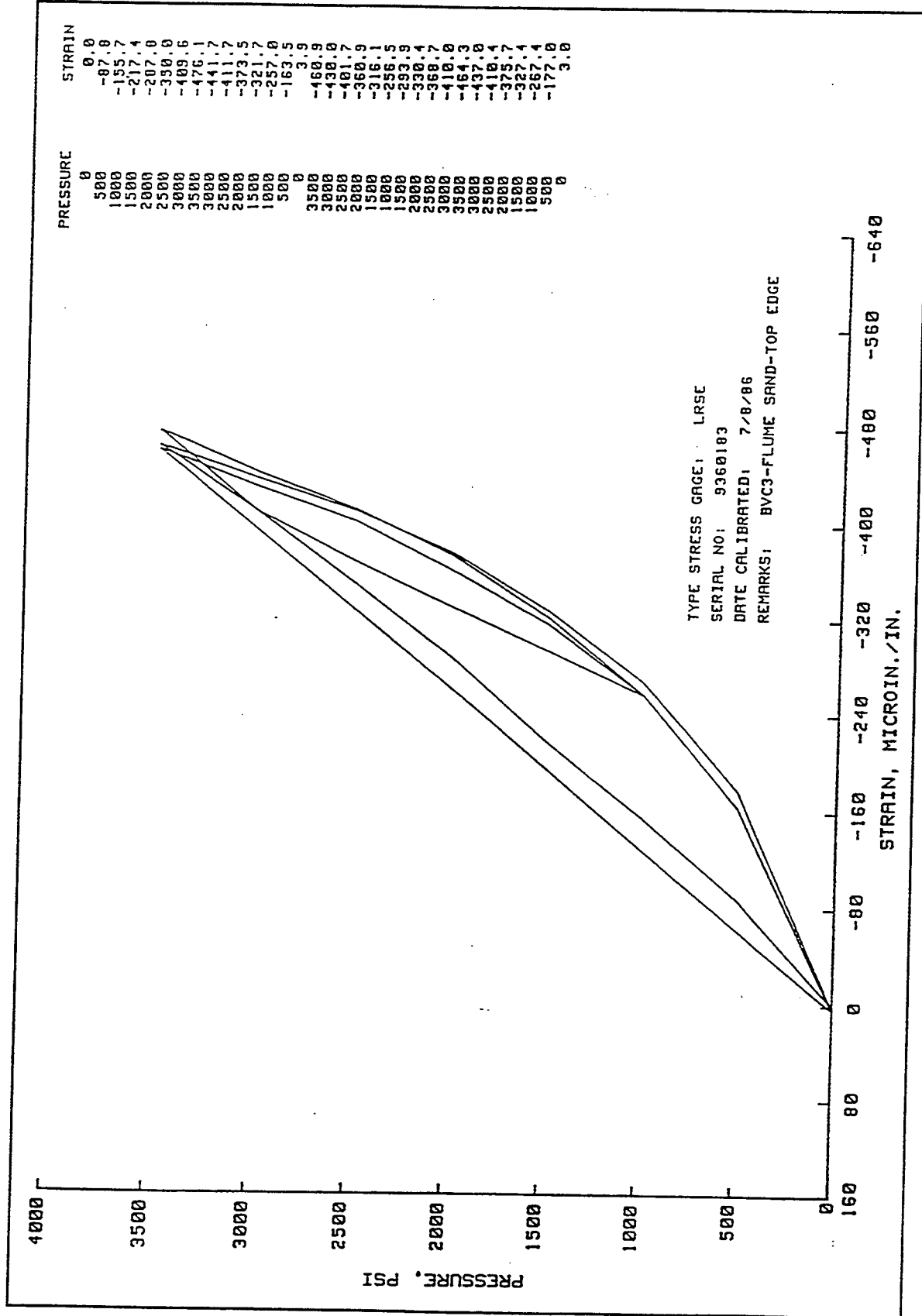
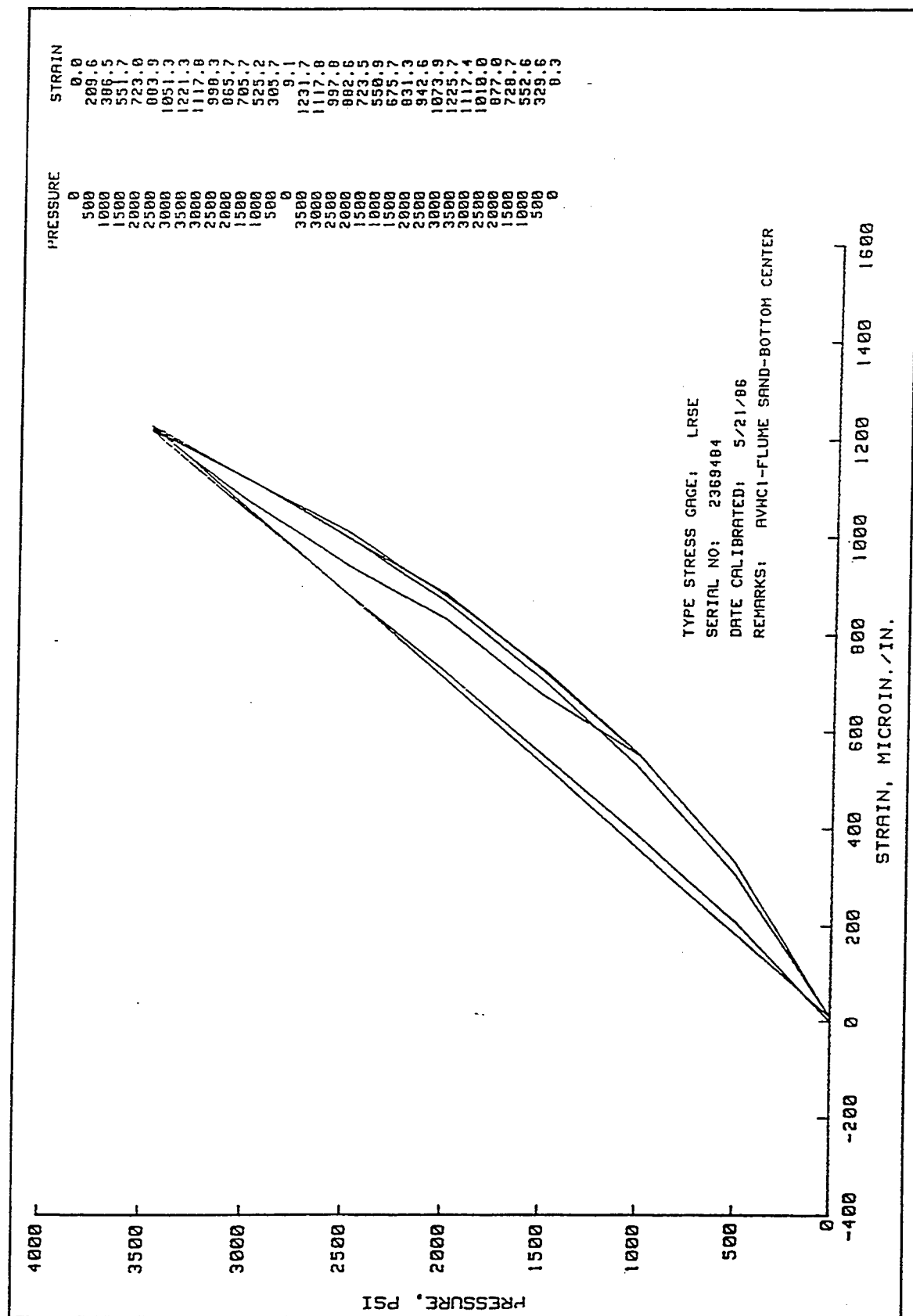


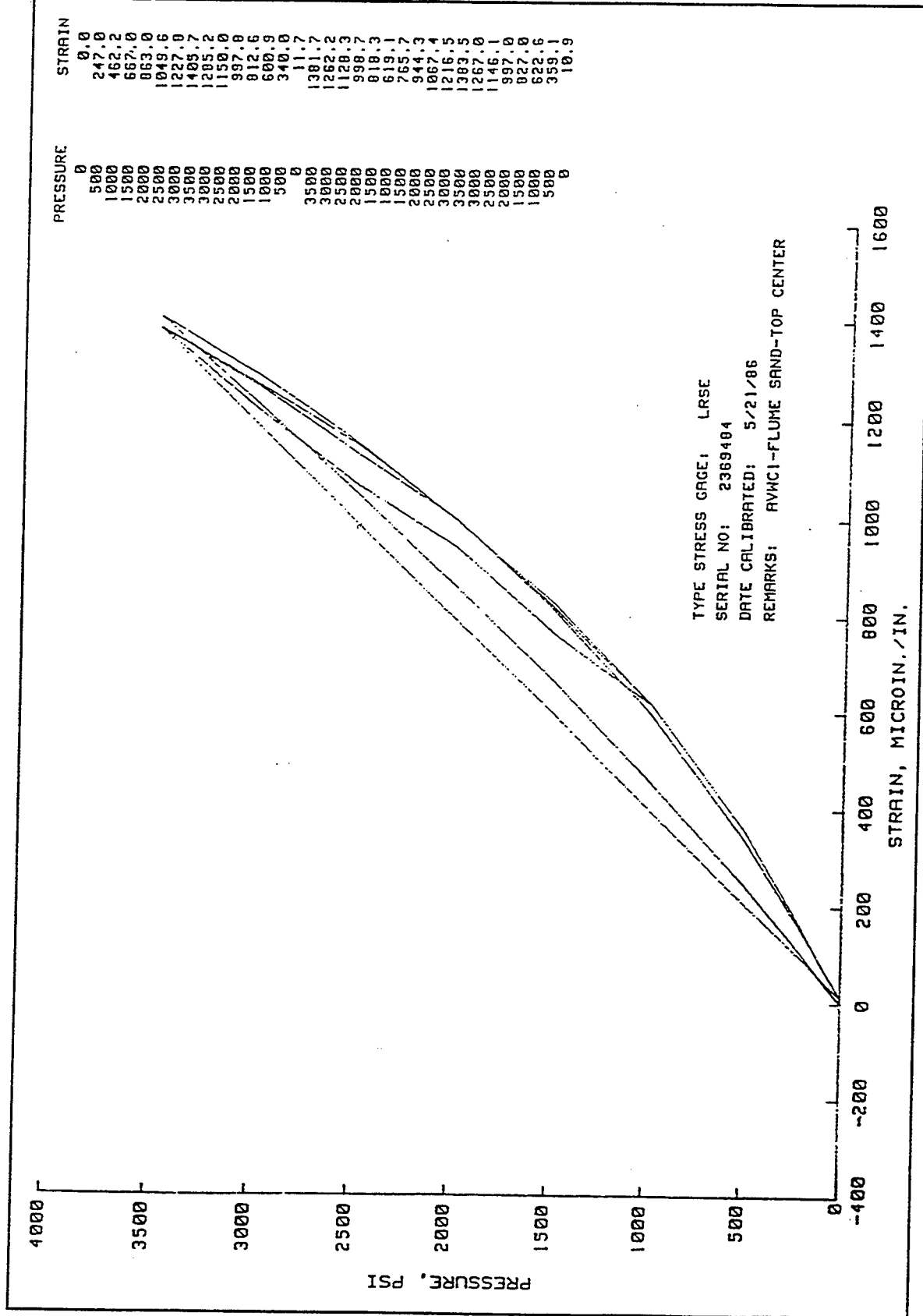
Plate 116

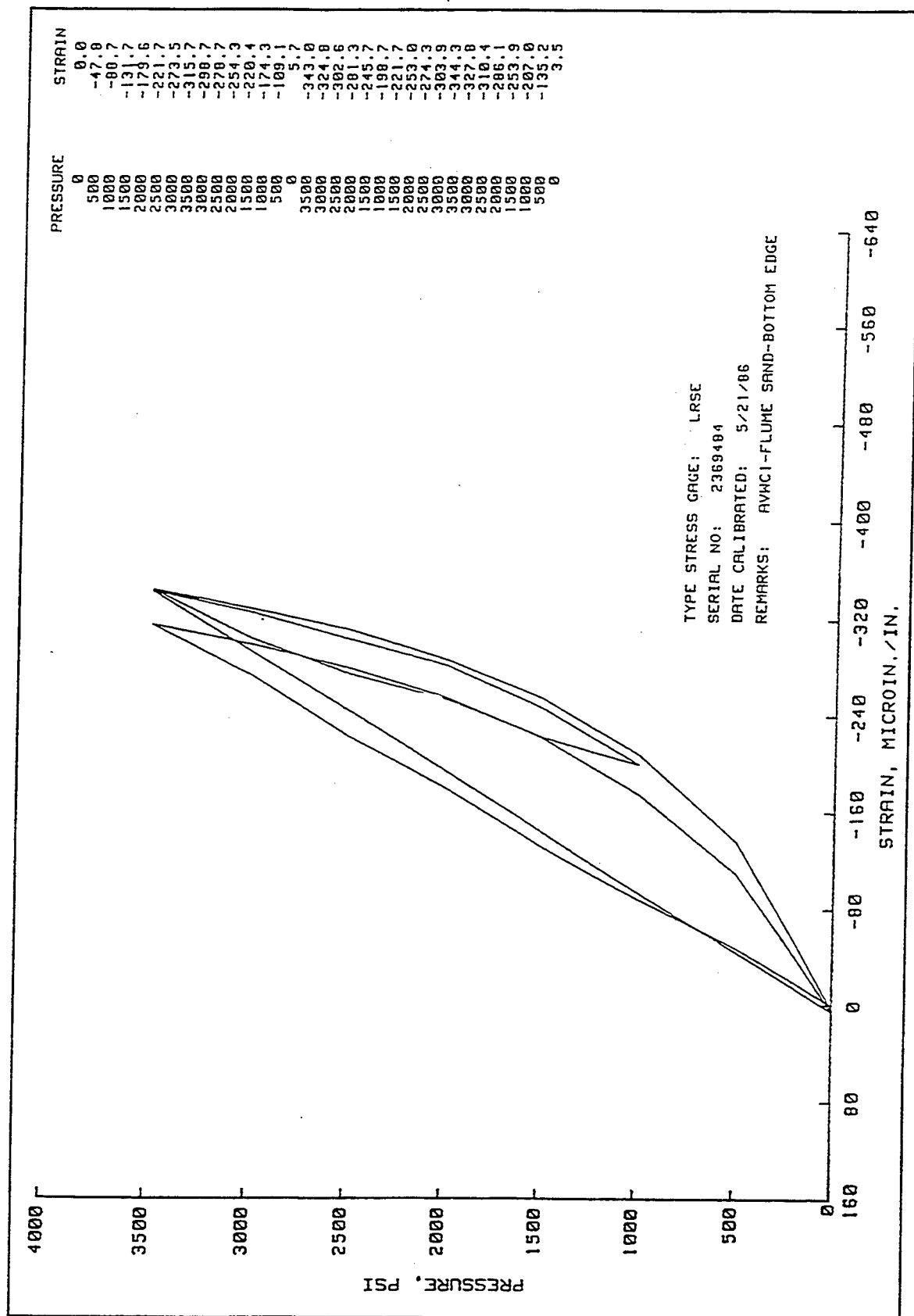


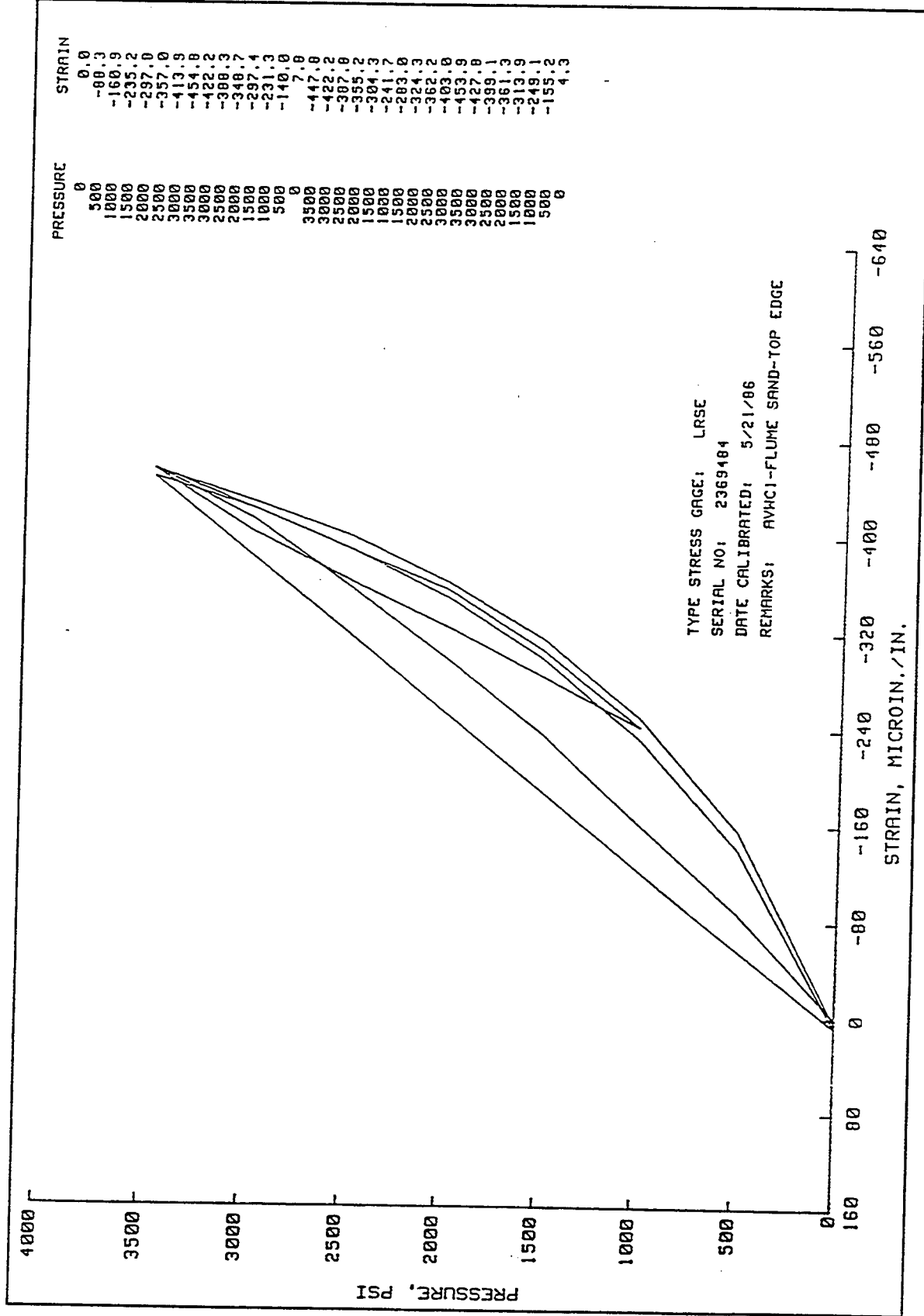


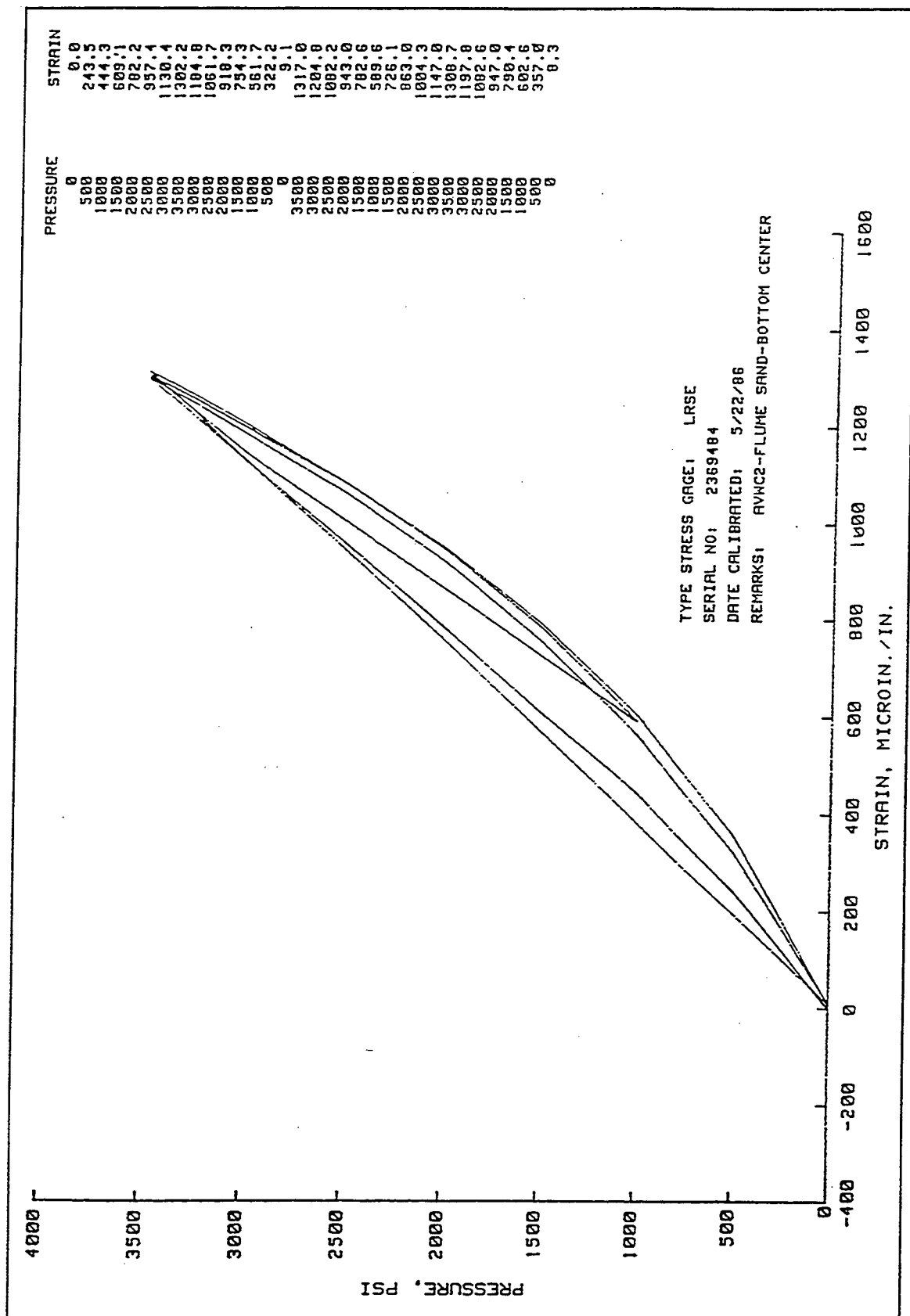


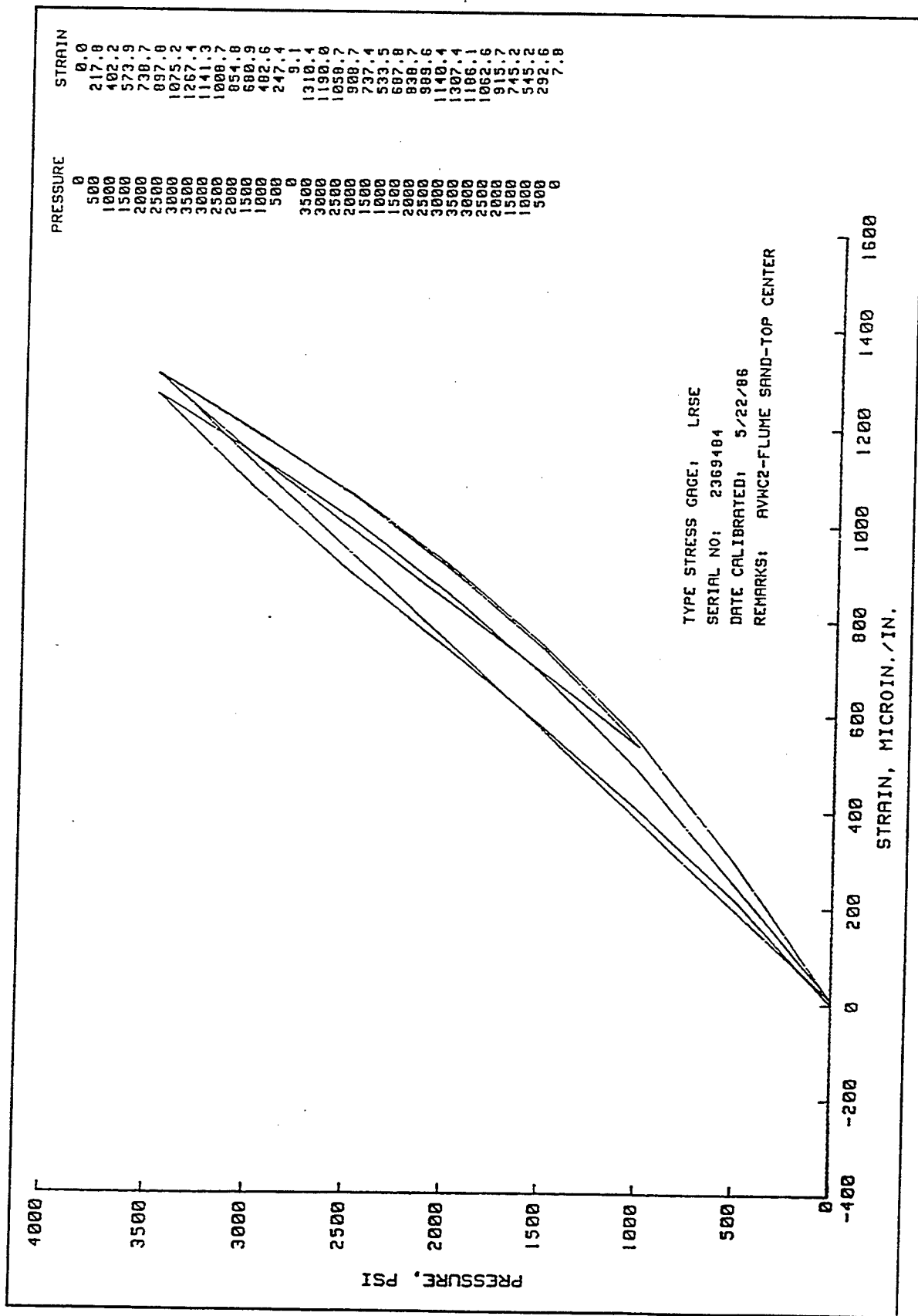


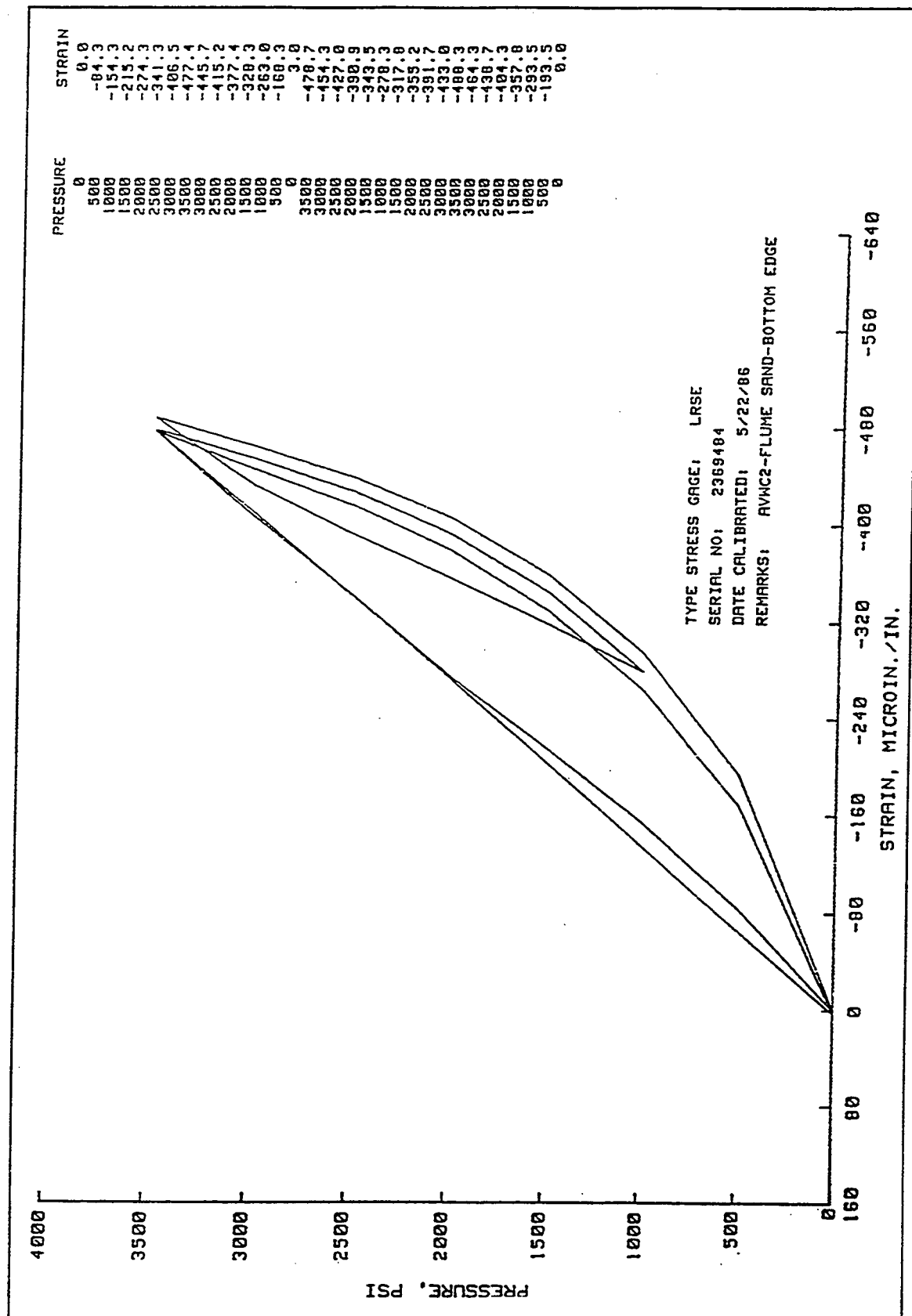


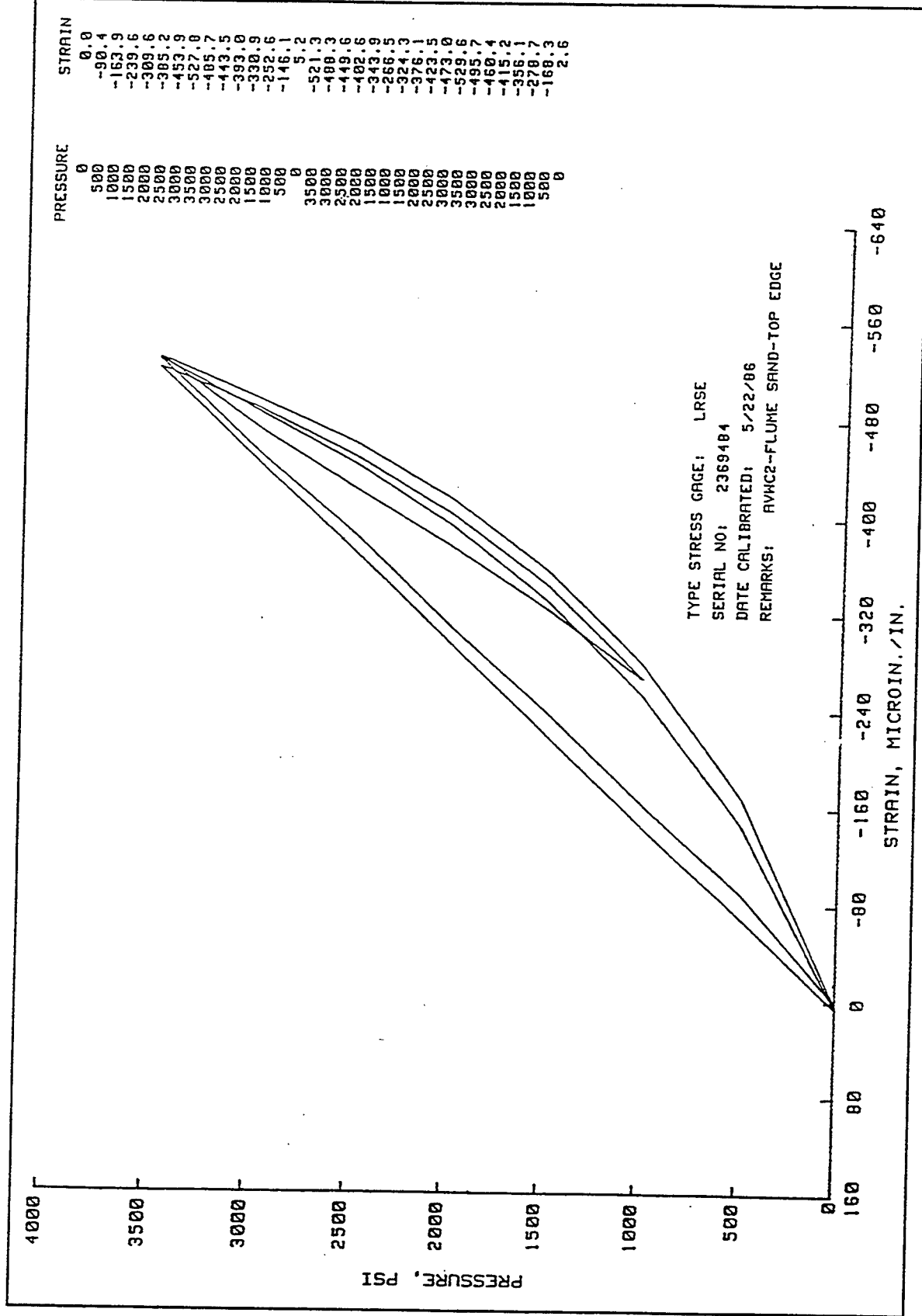


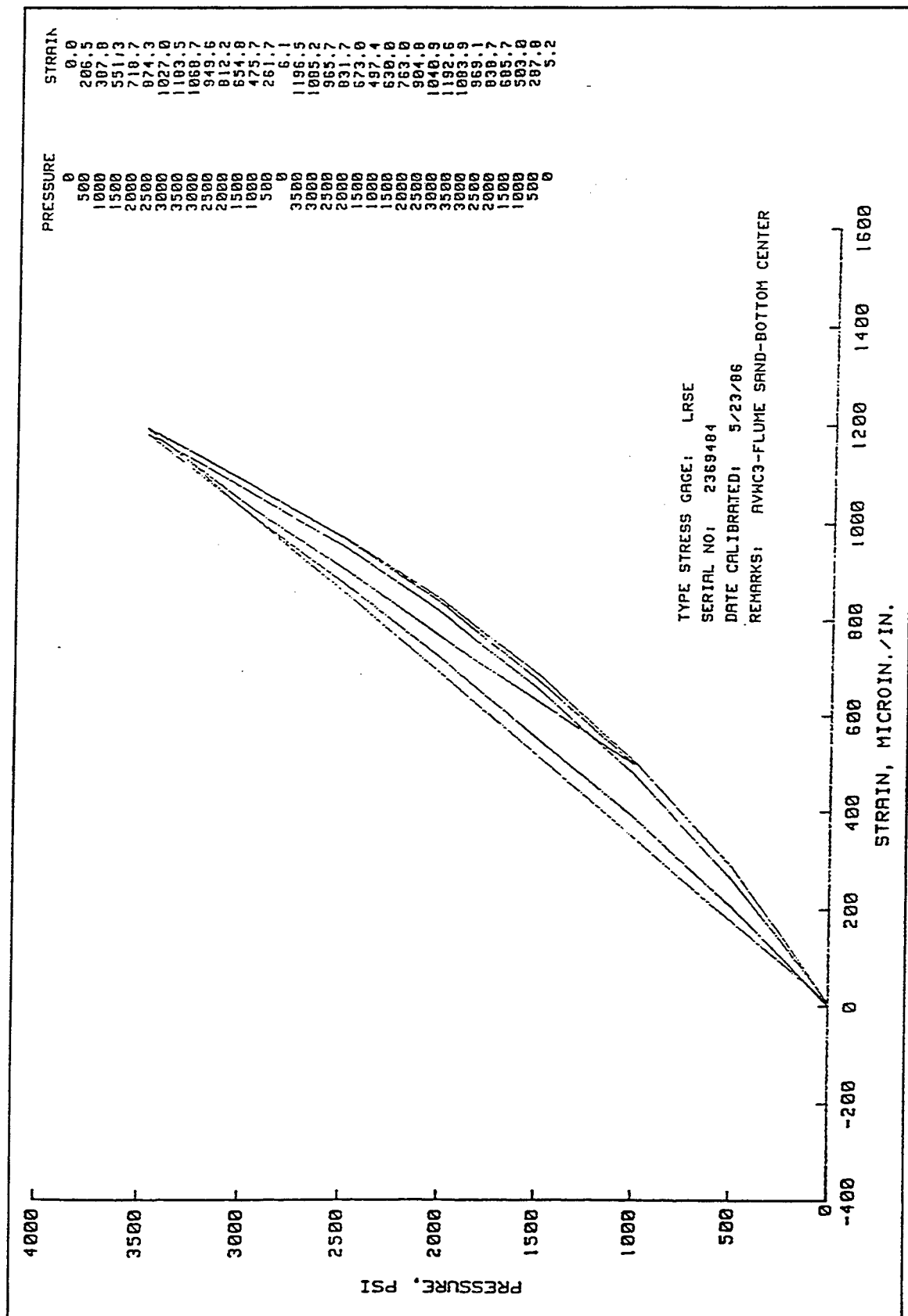




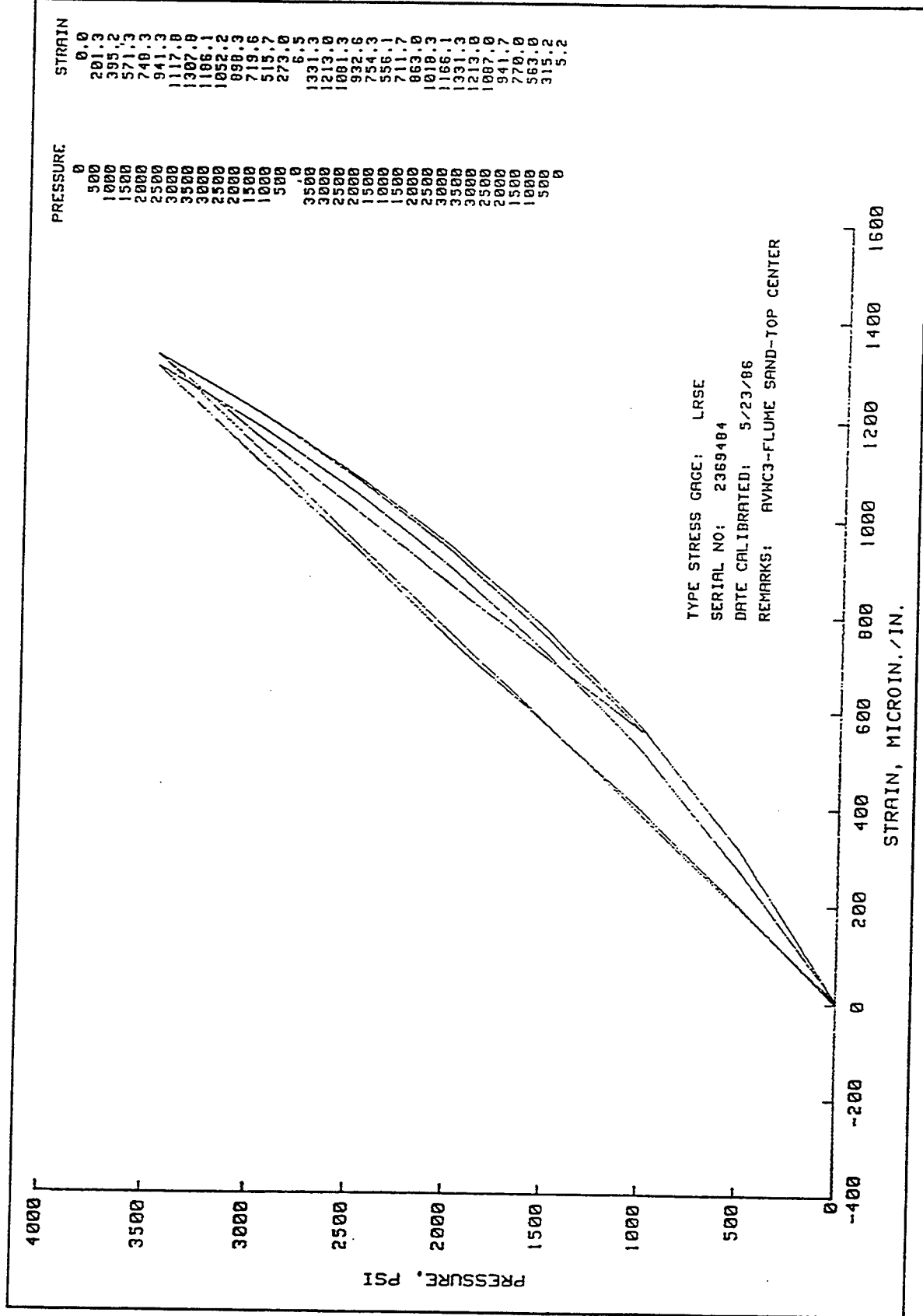


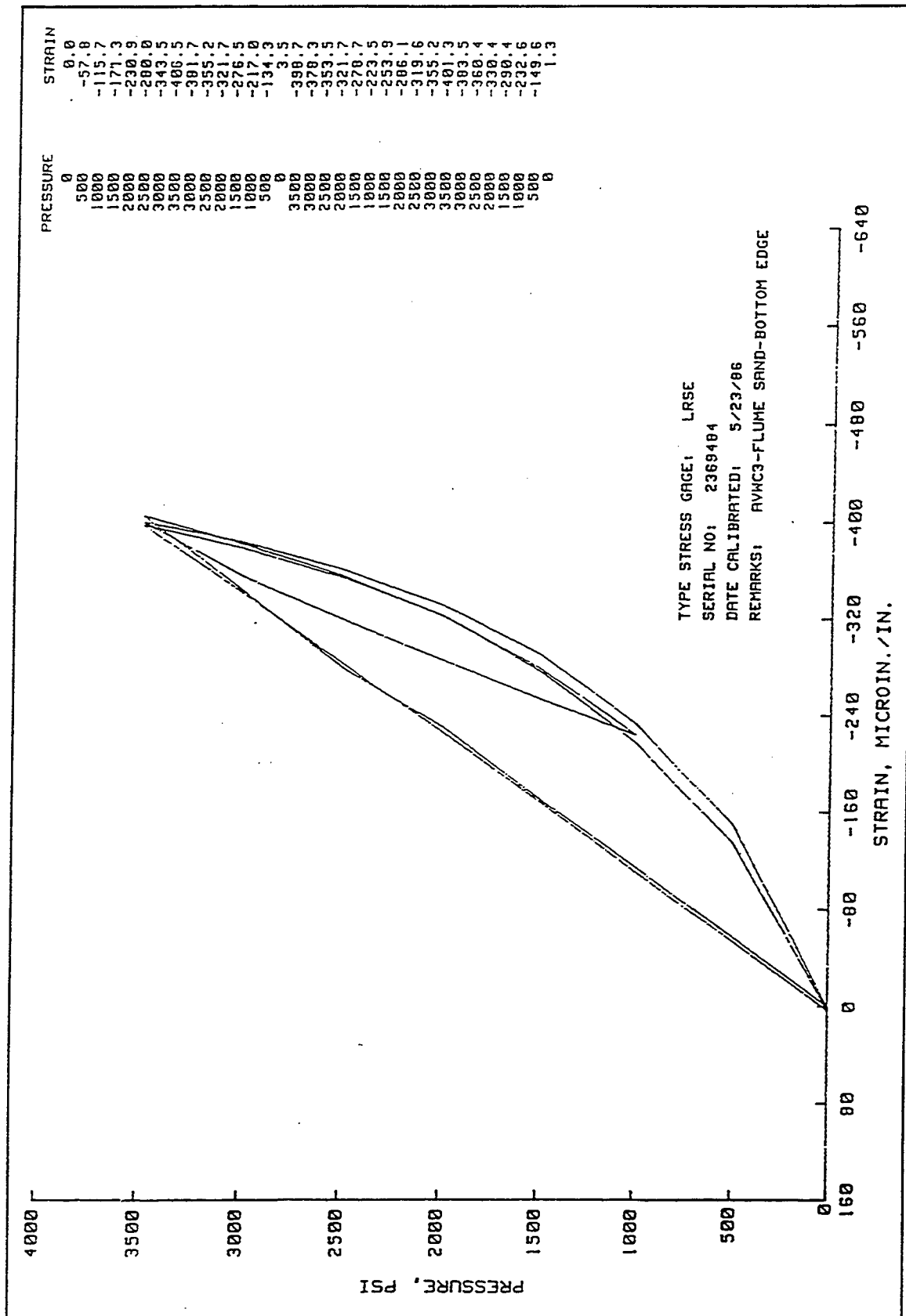


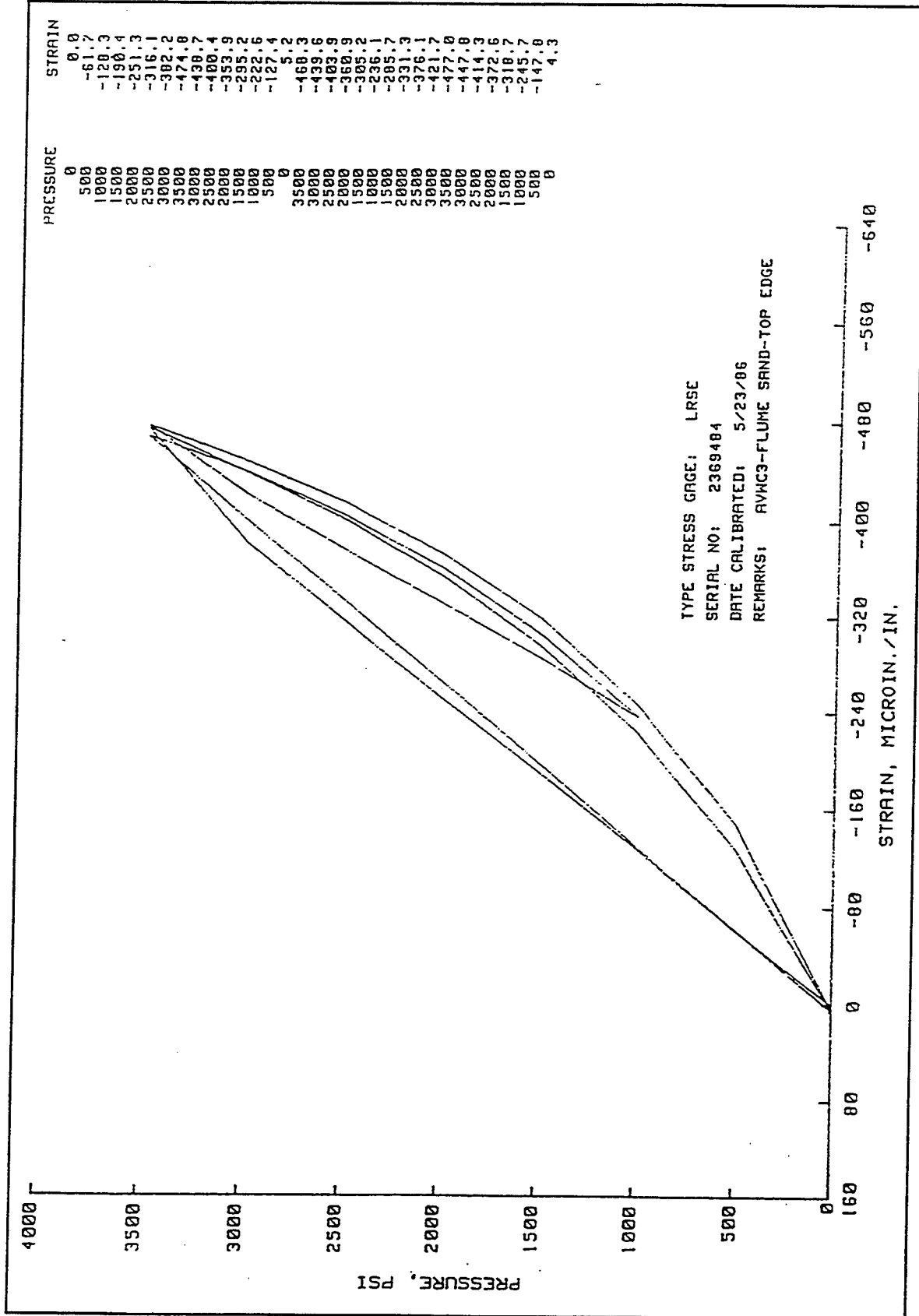


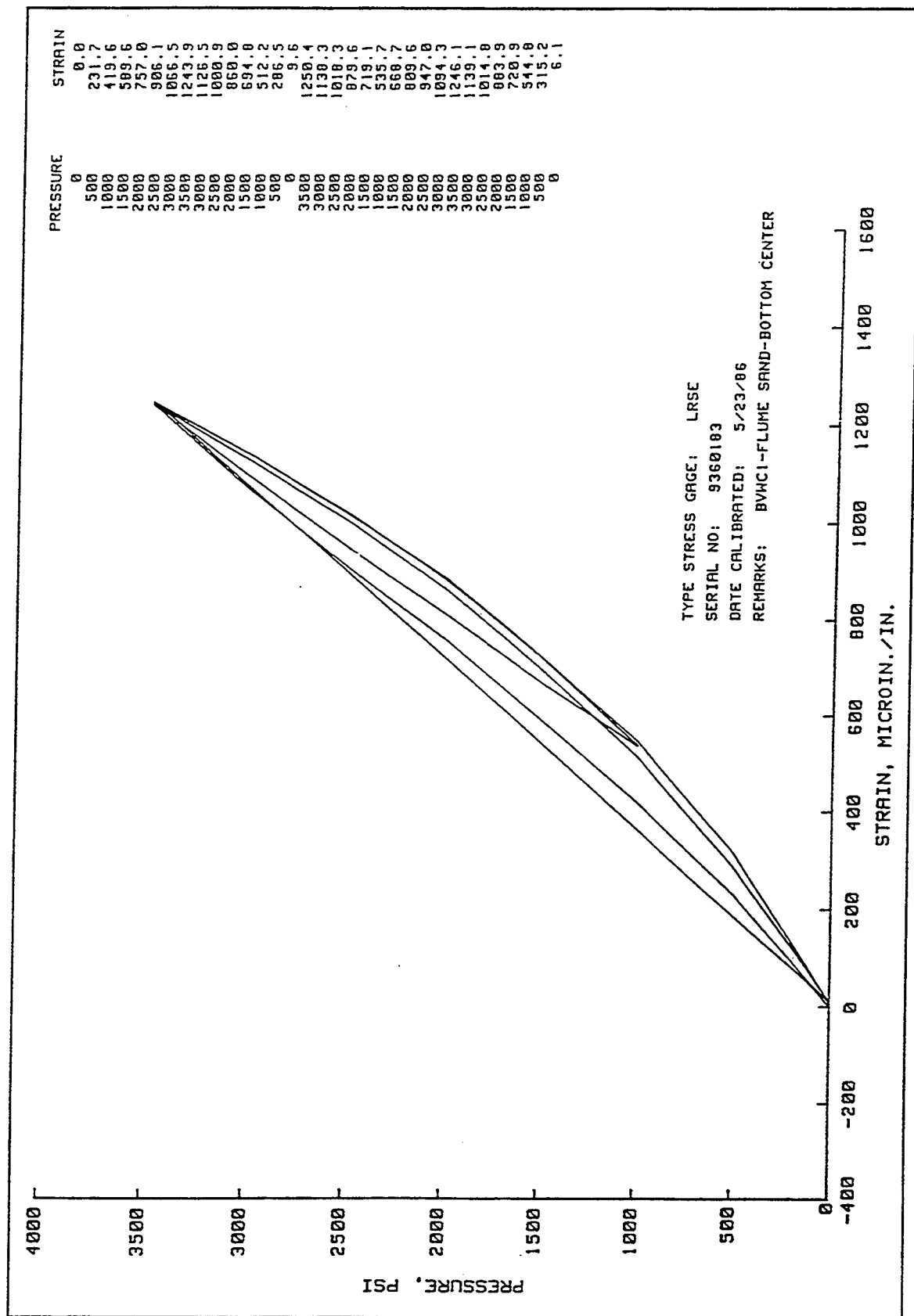












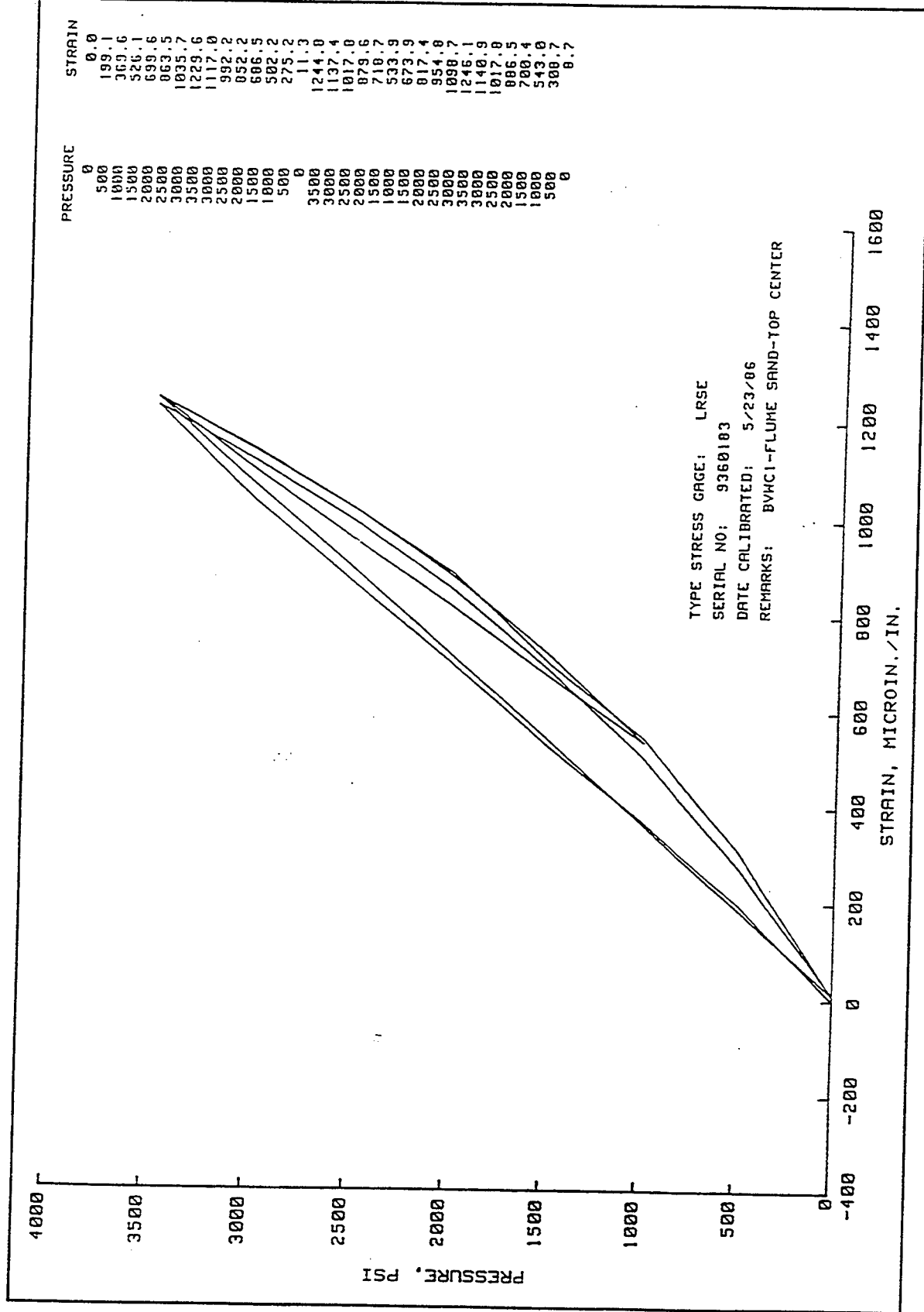
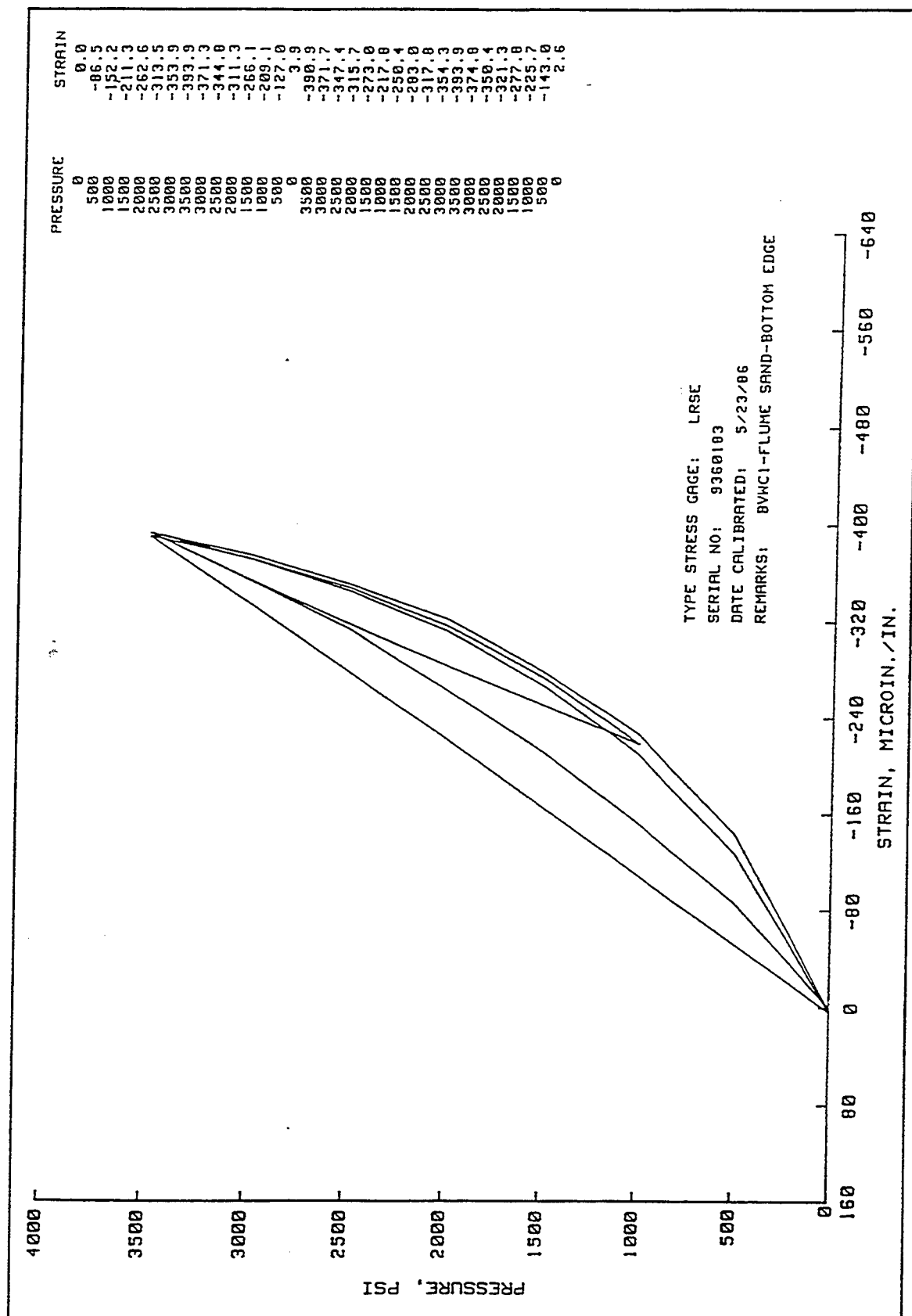
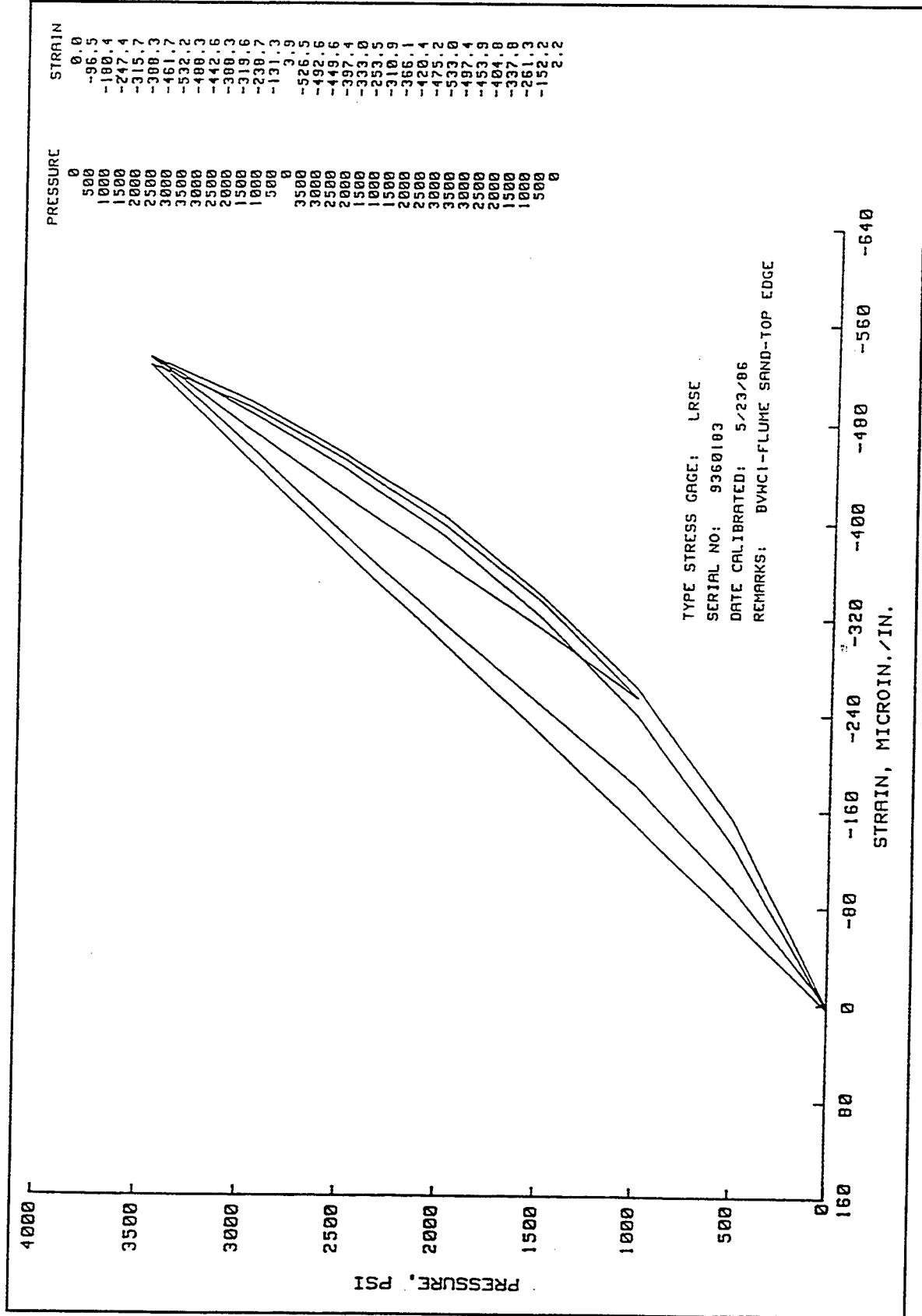
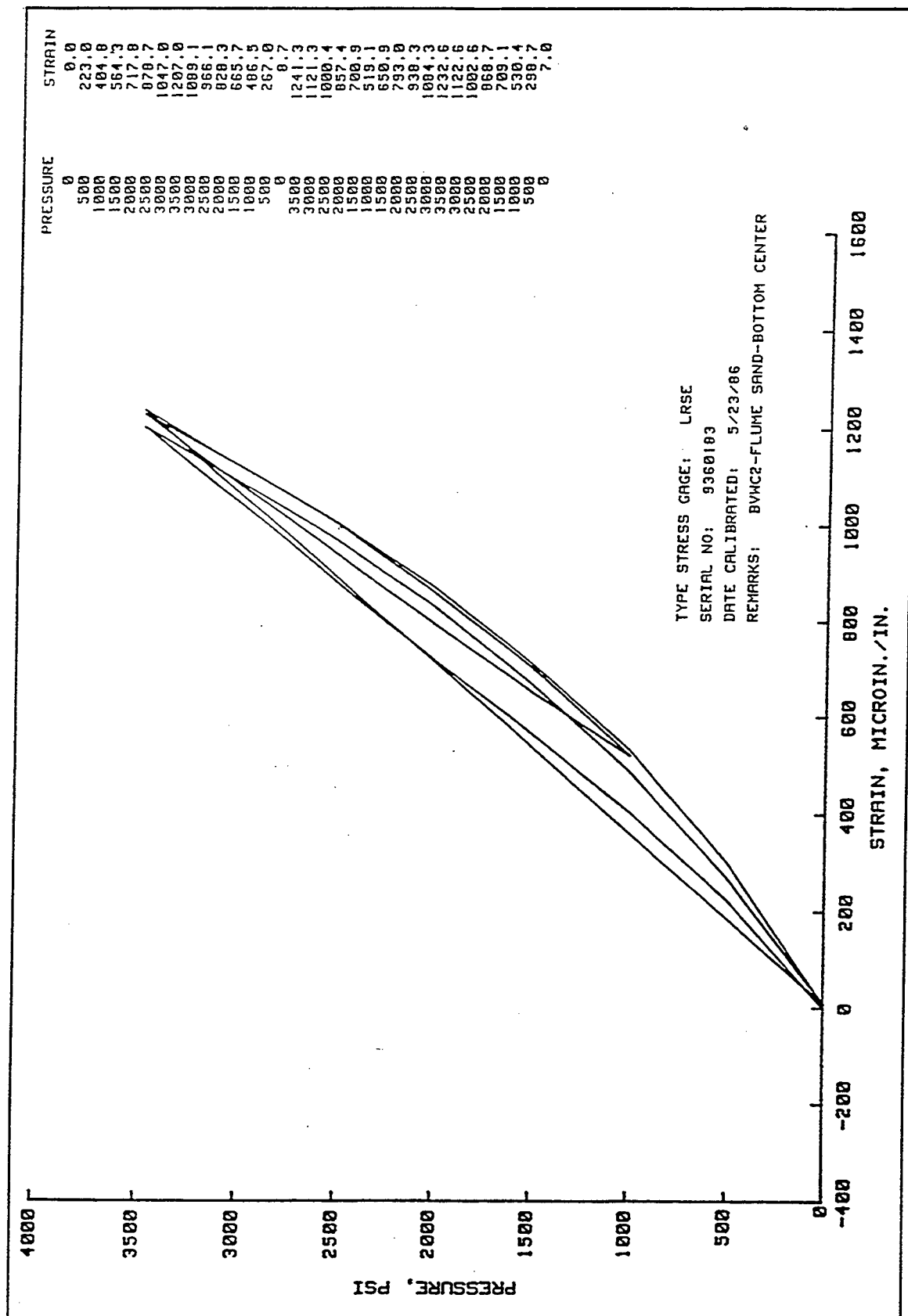


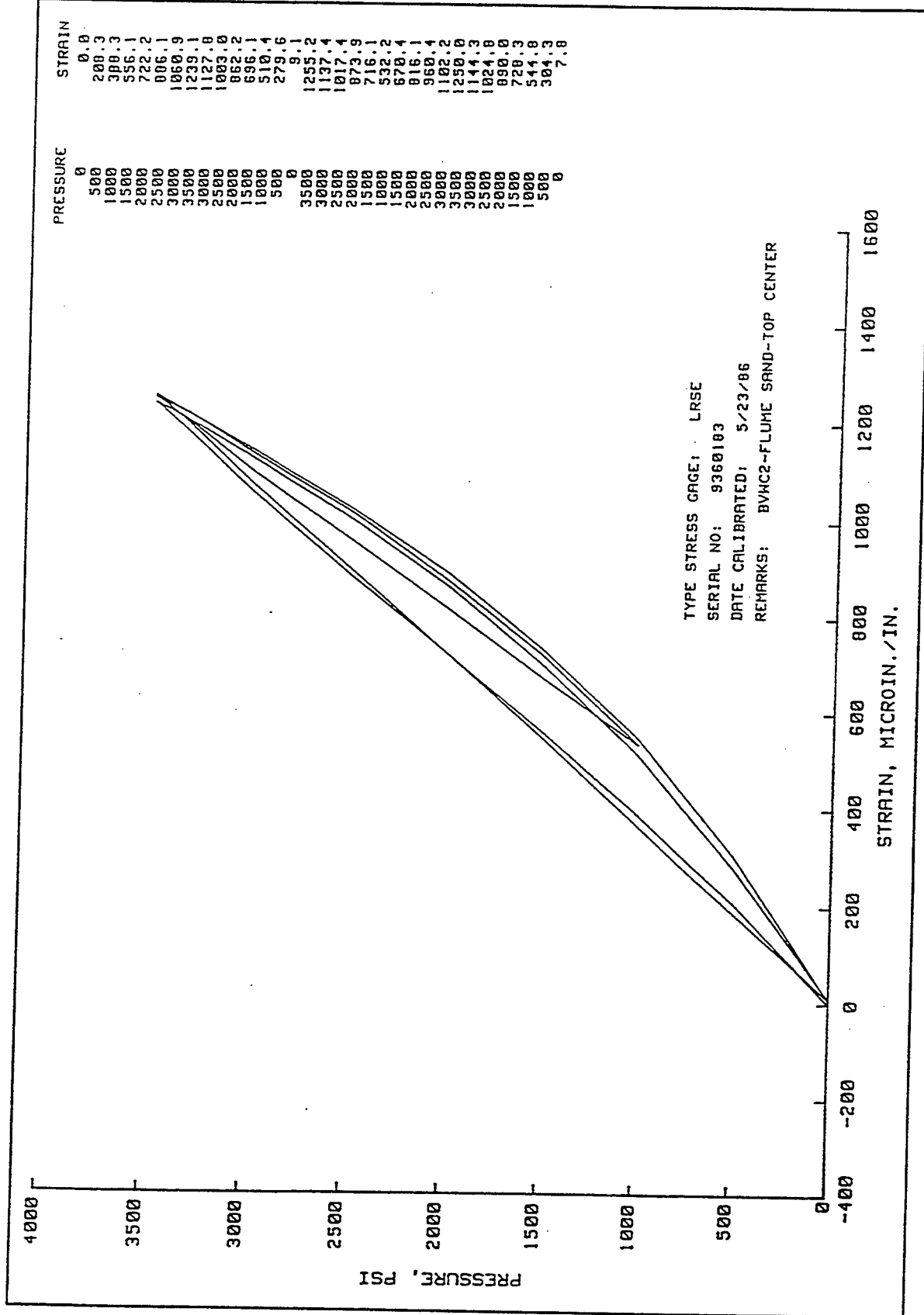
Plate 132

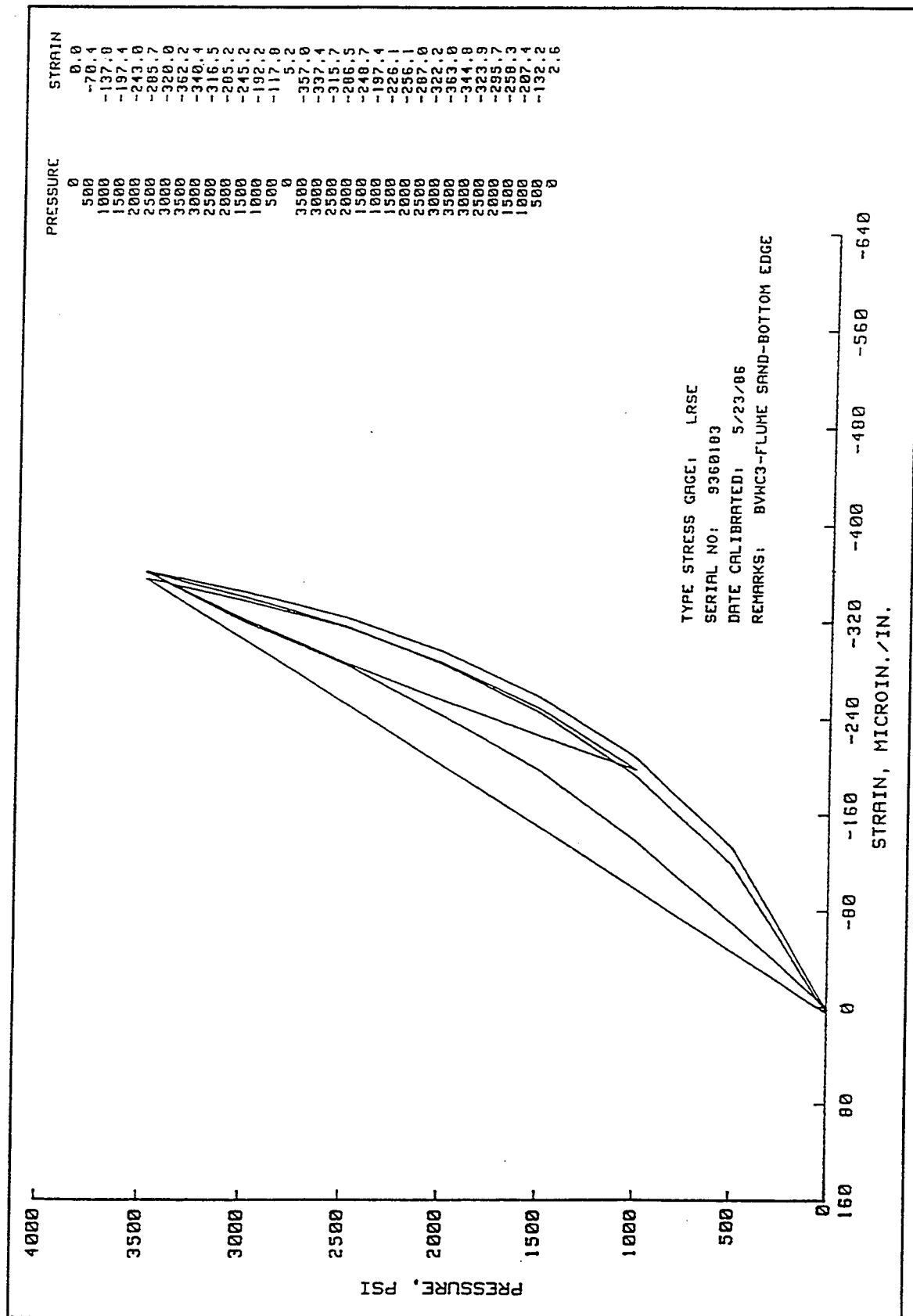


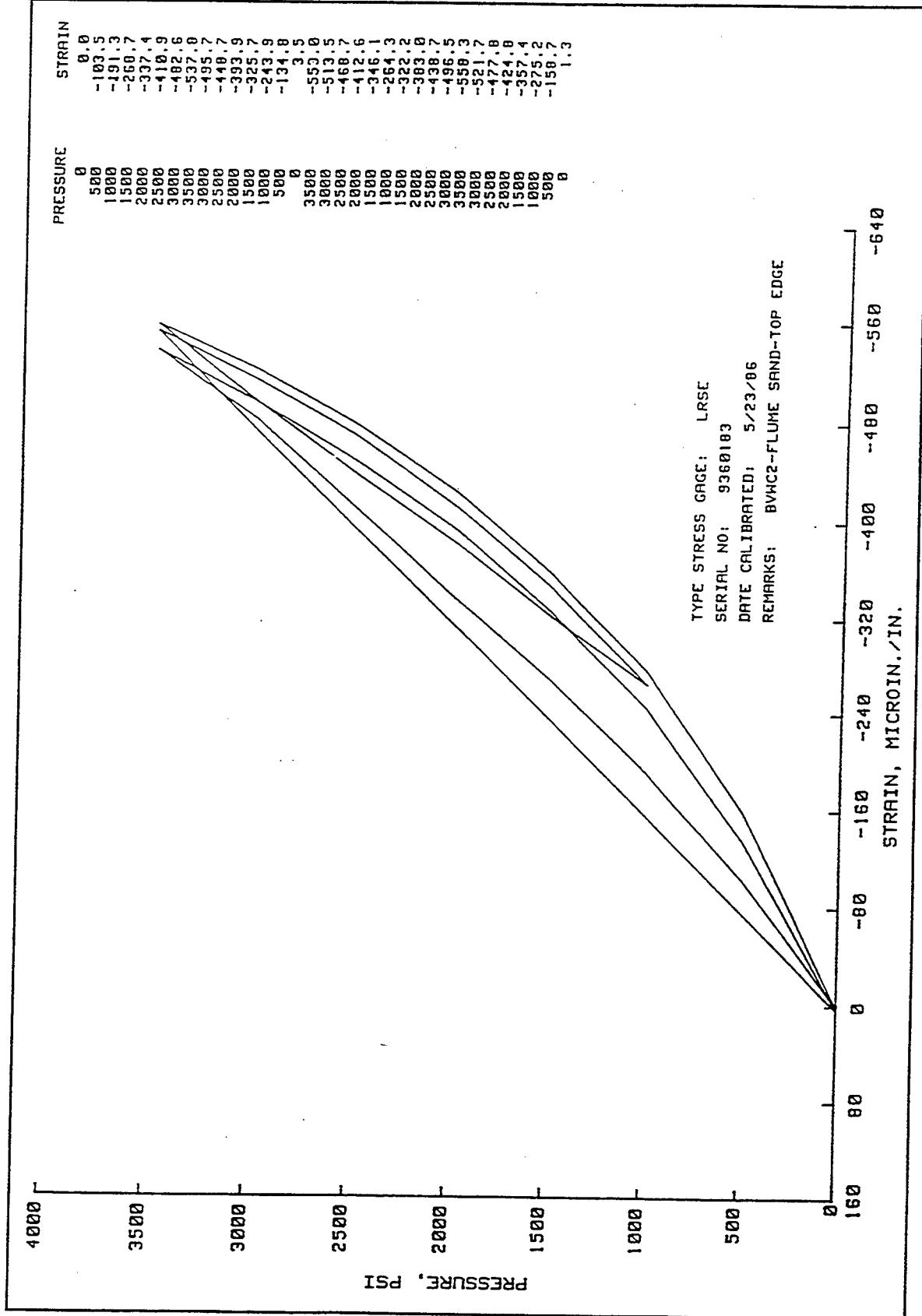


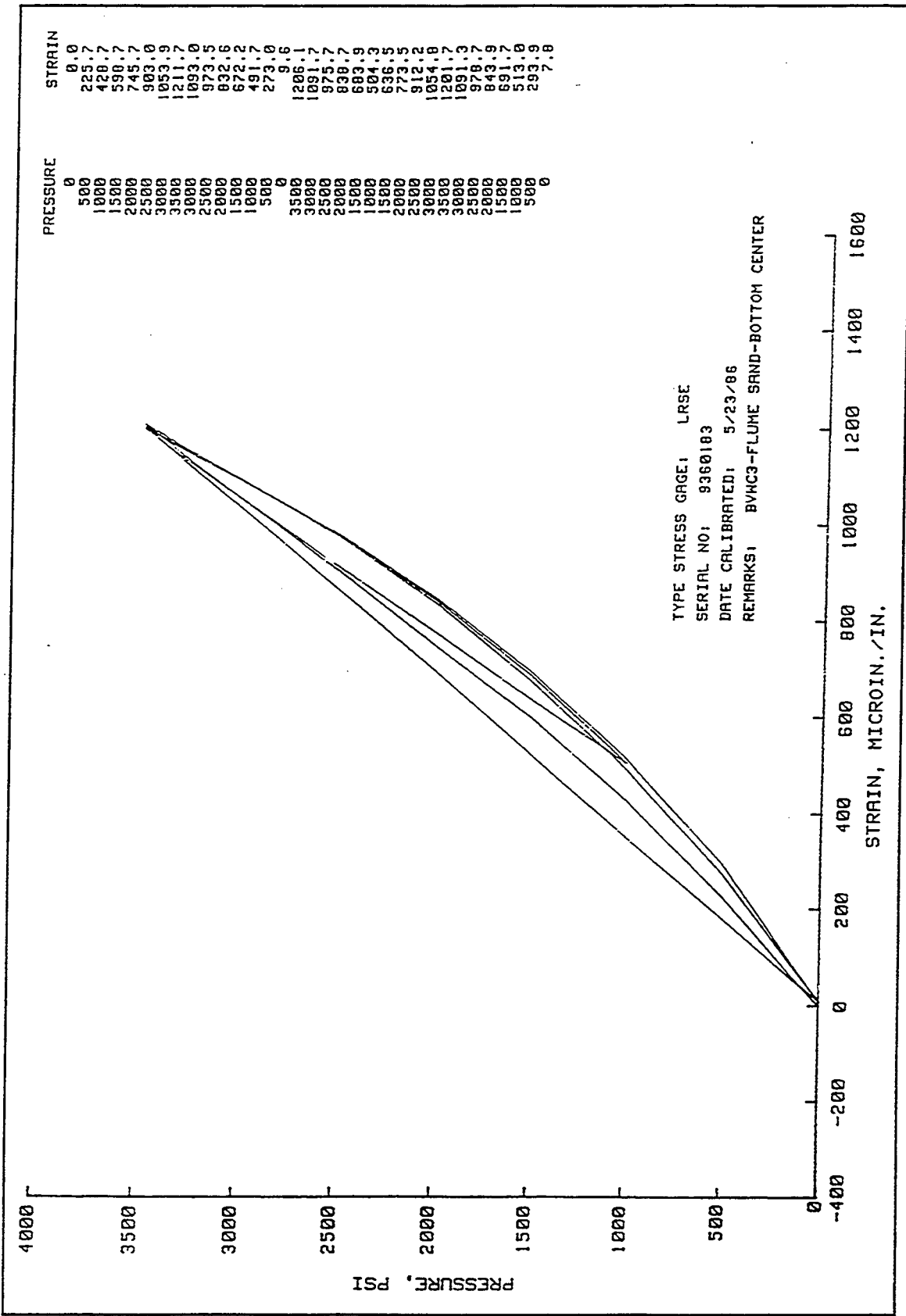












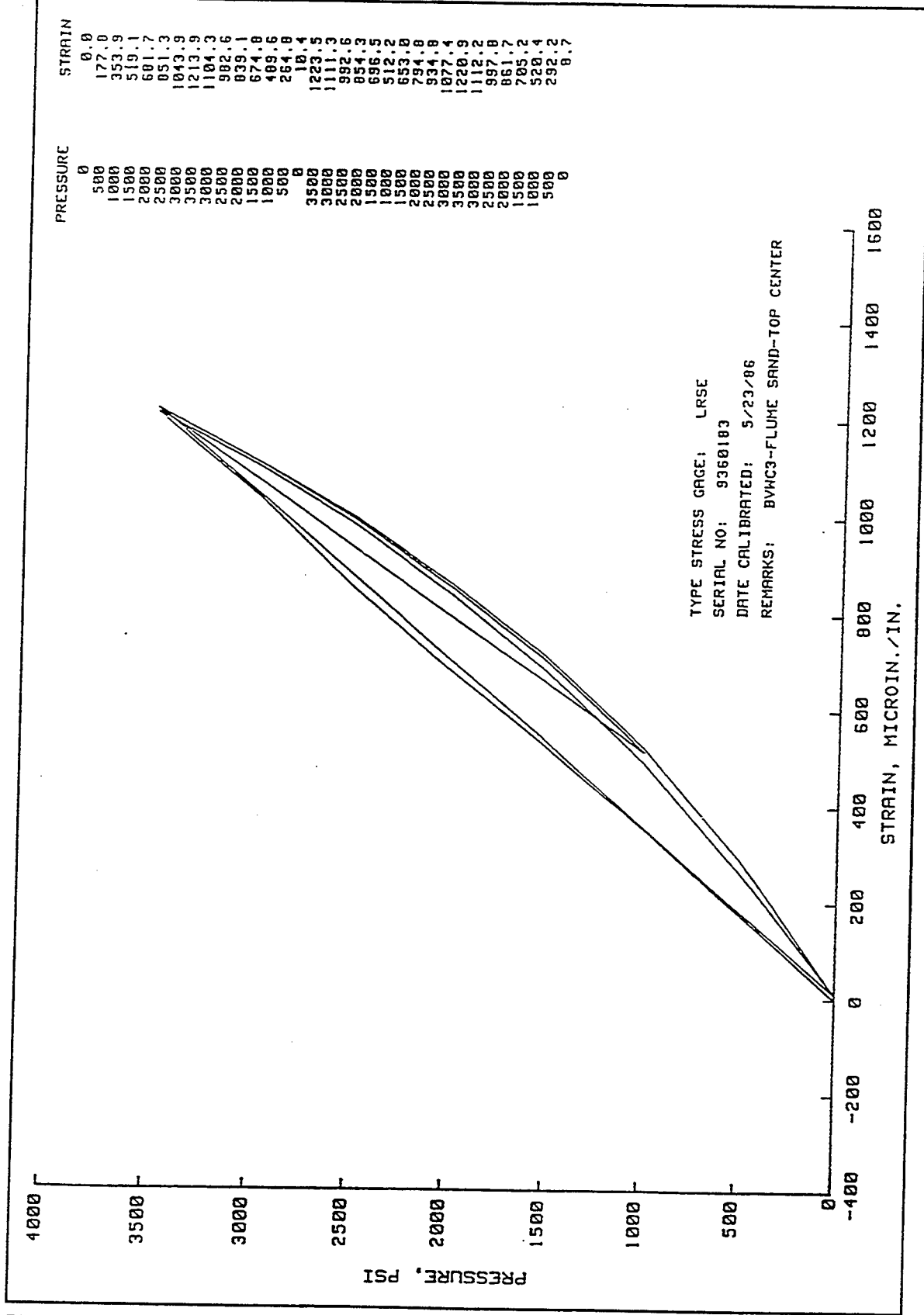
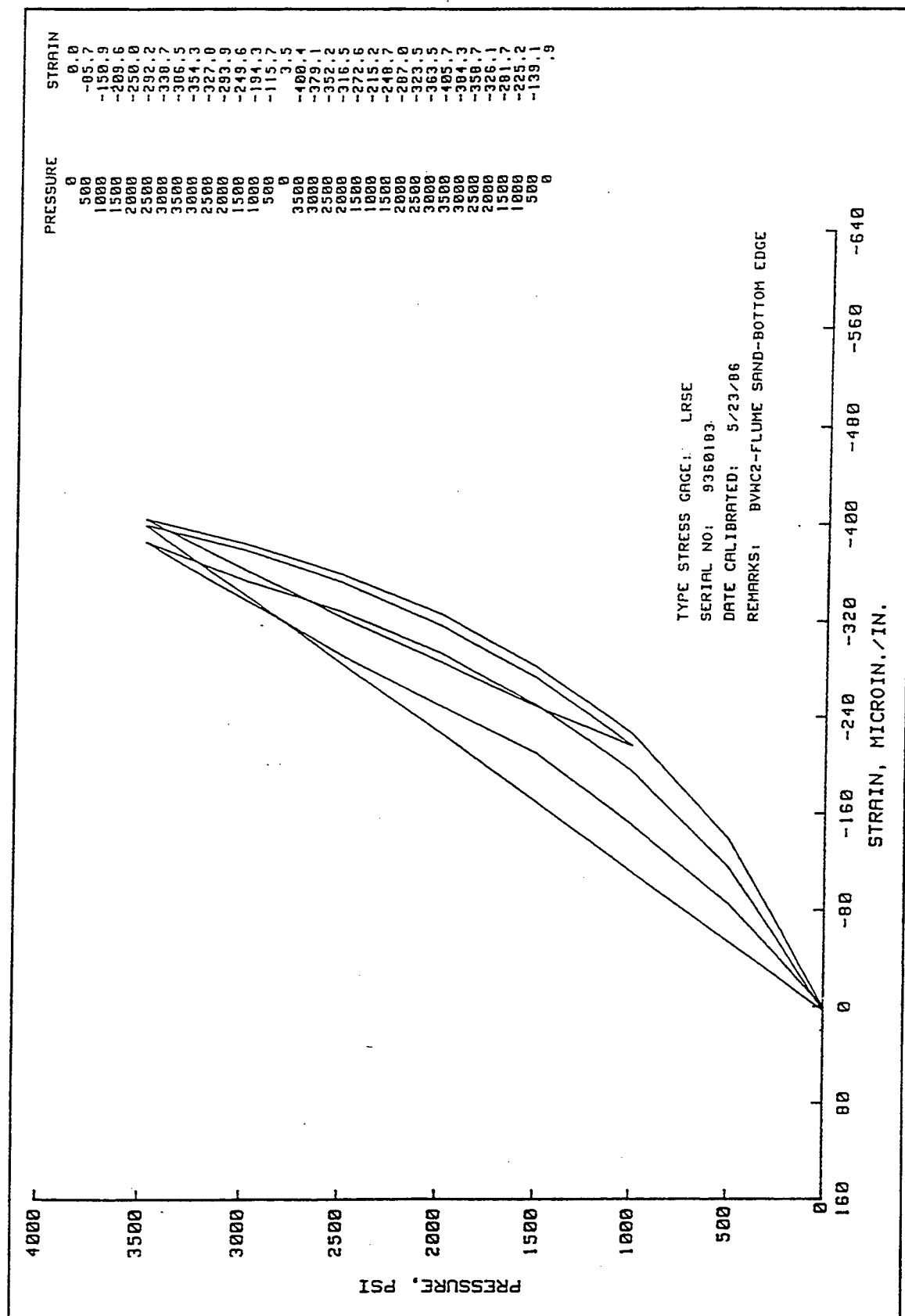
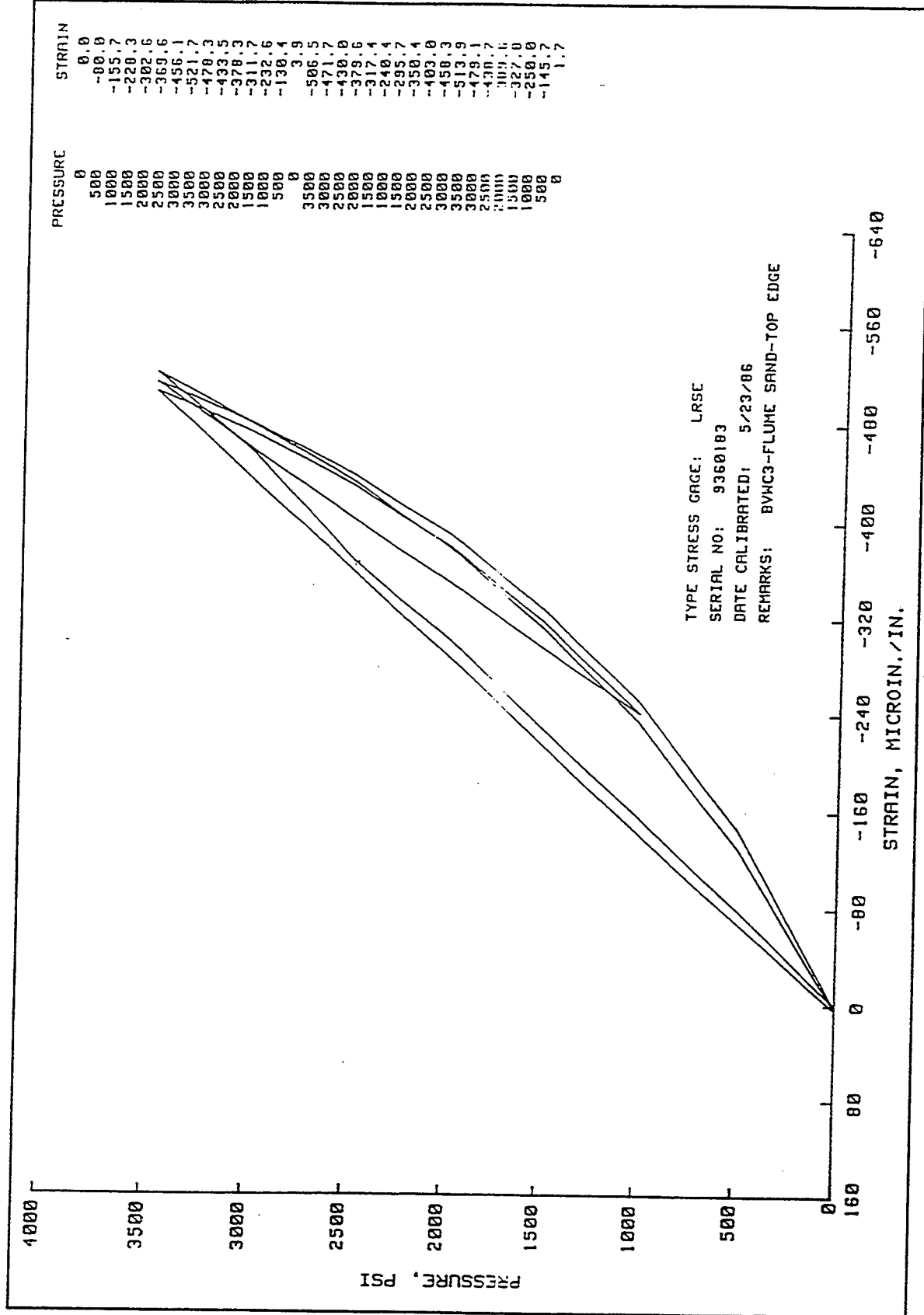
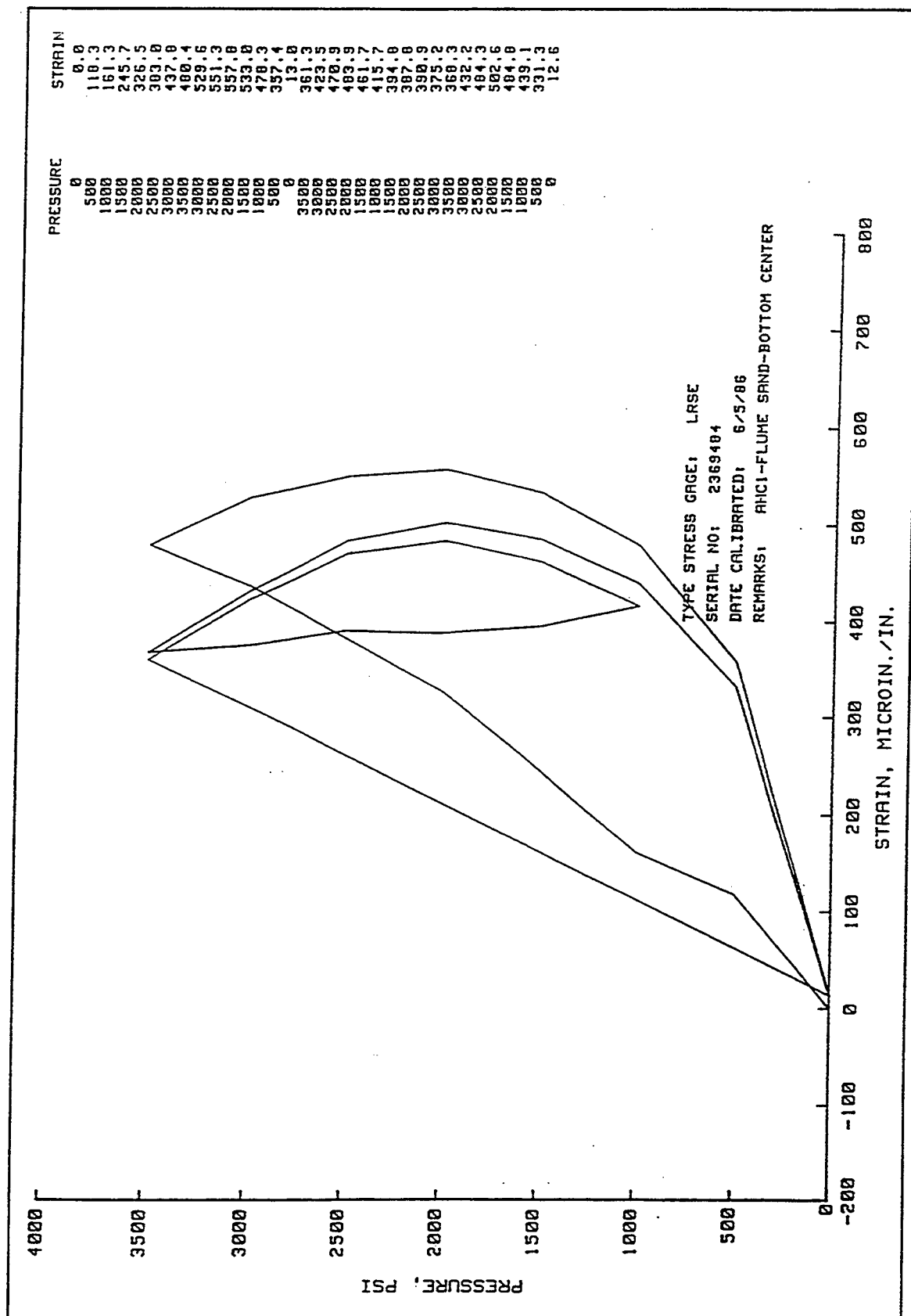


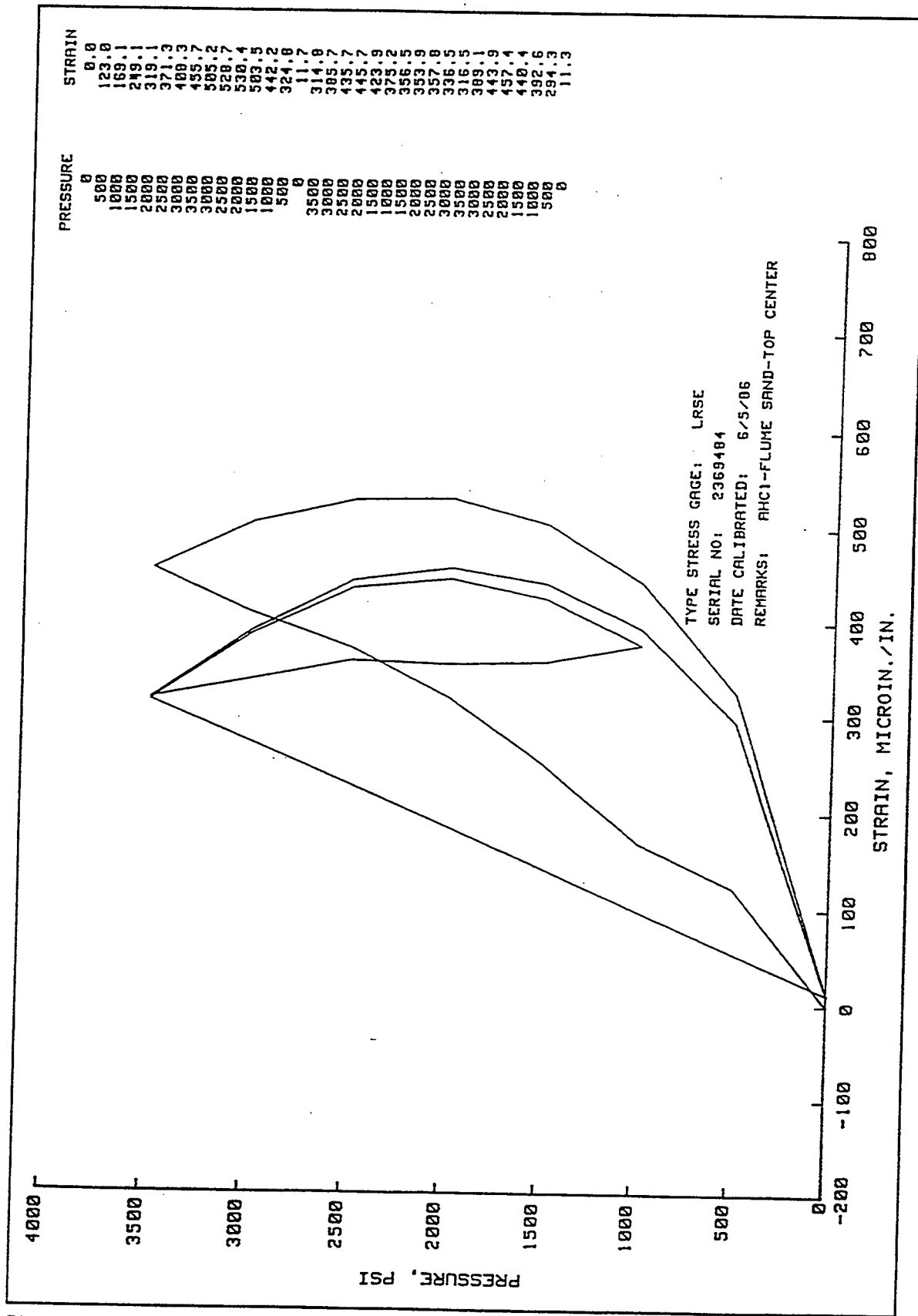
Plate 140

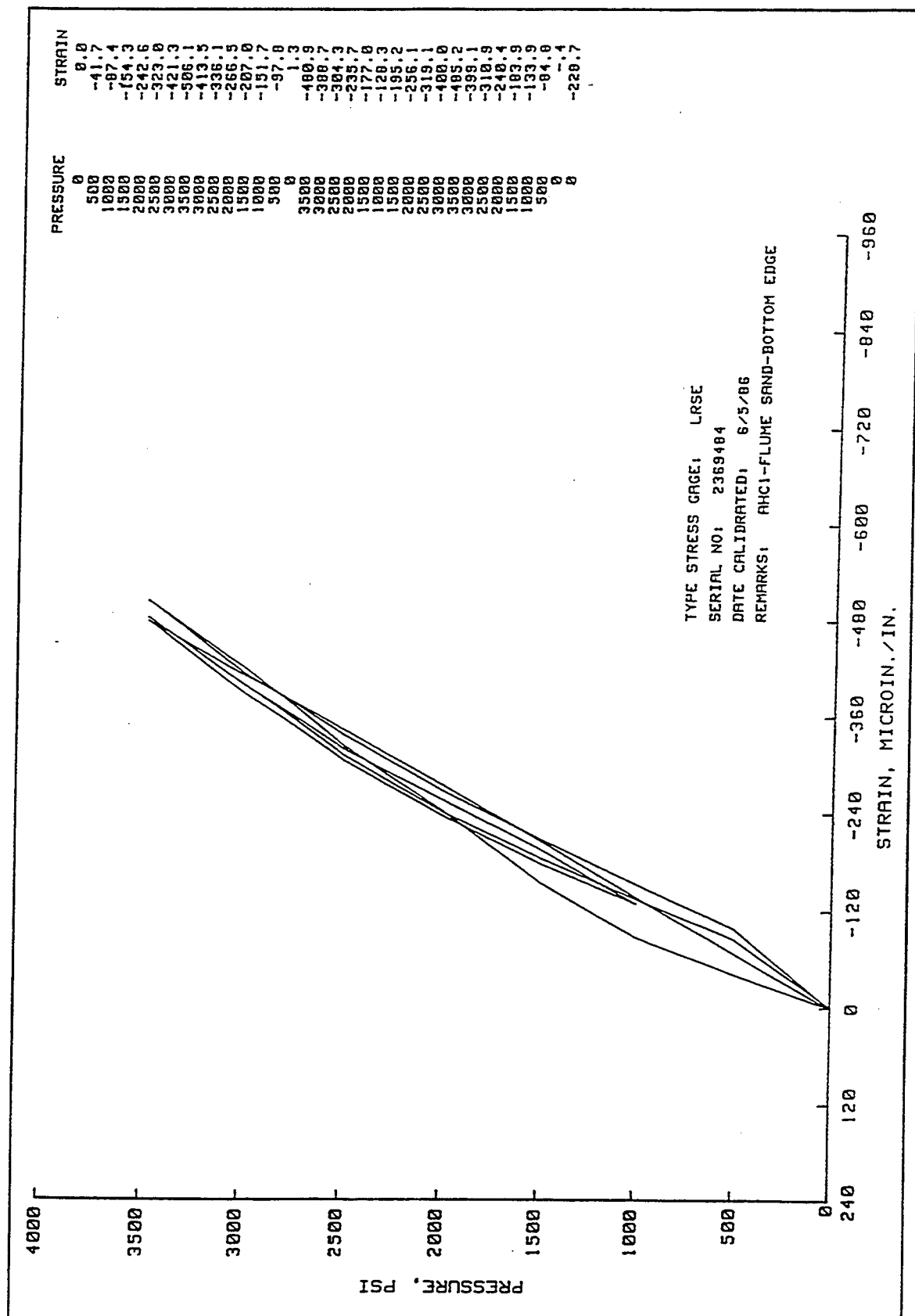


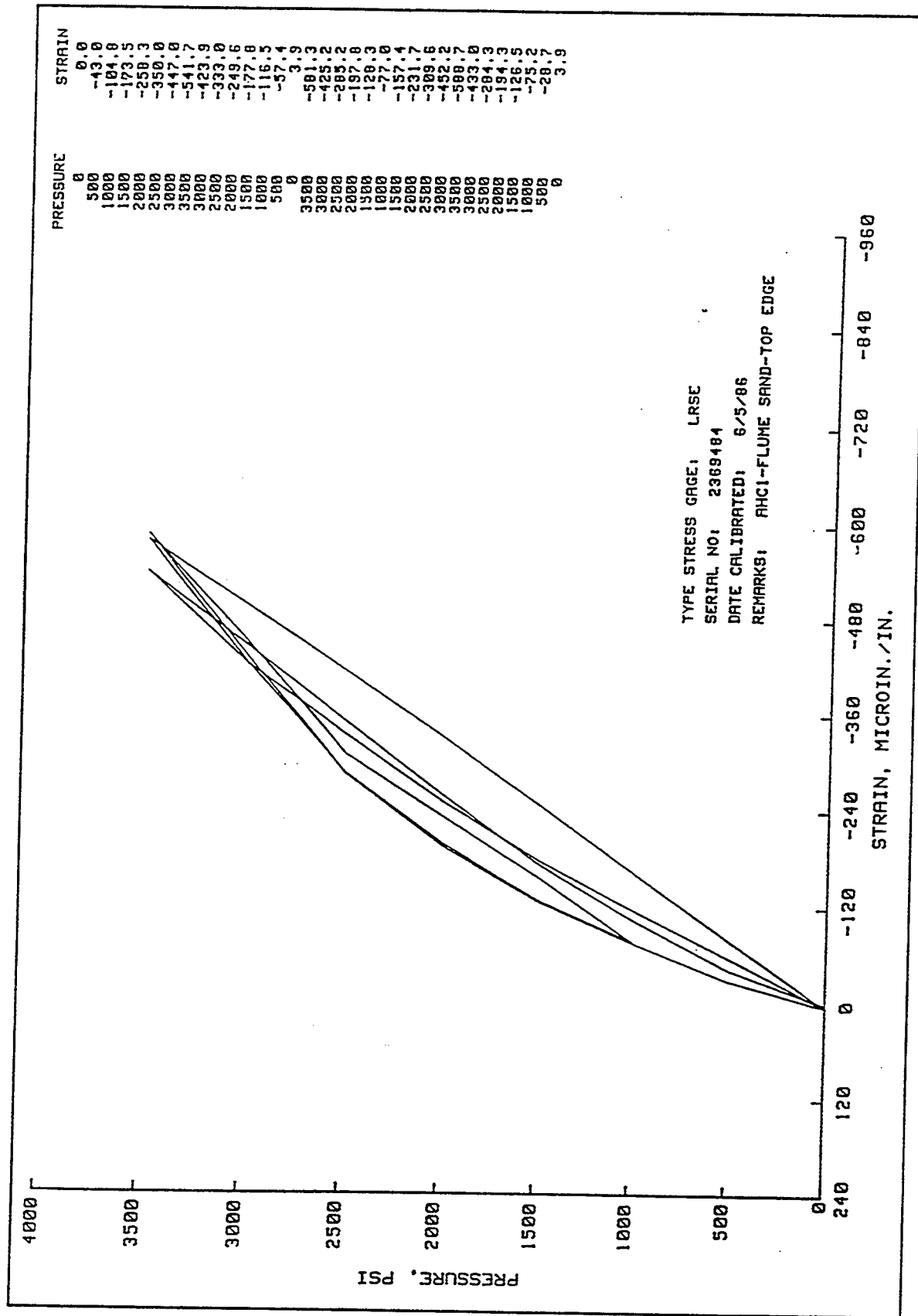


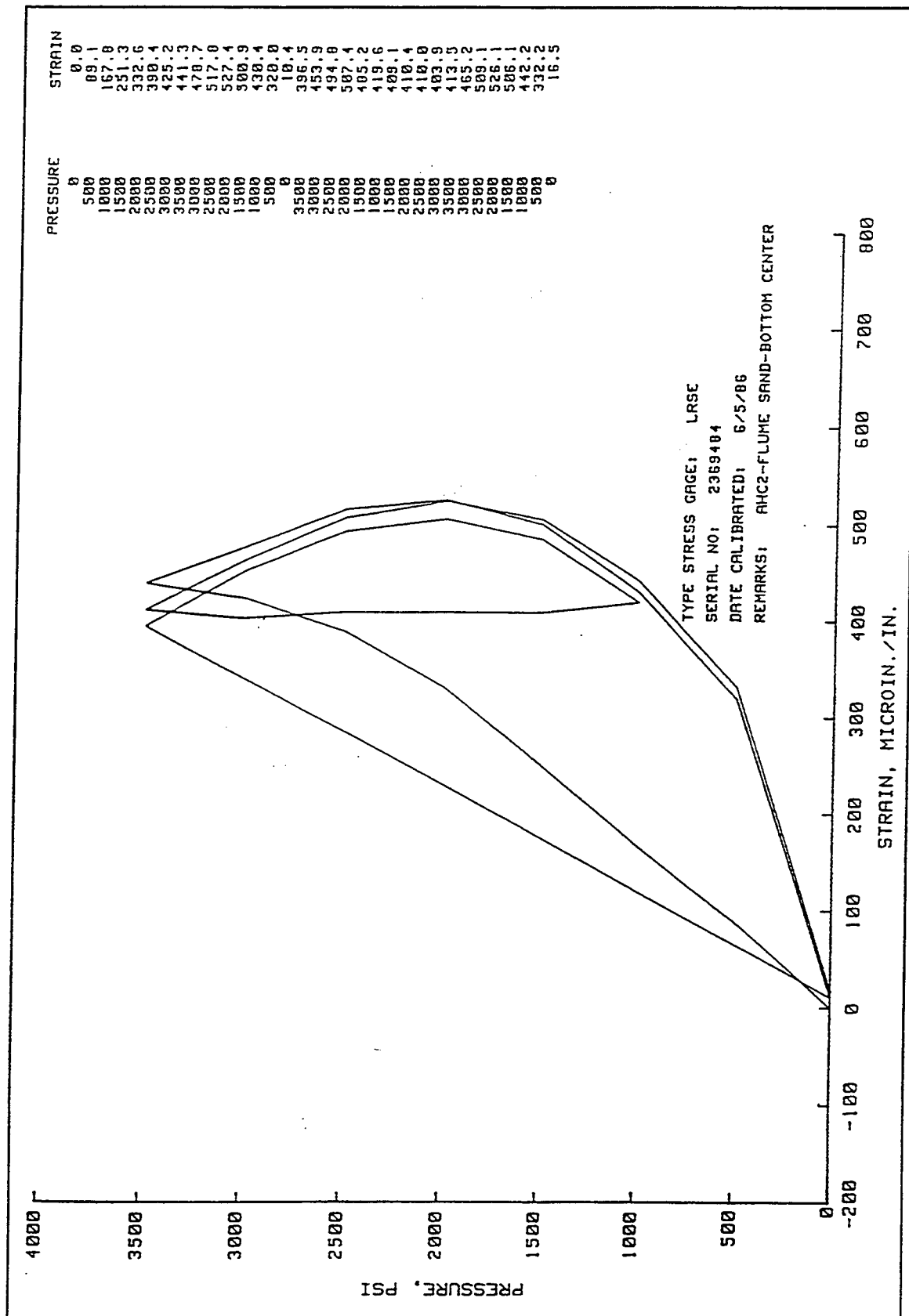












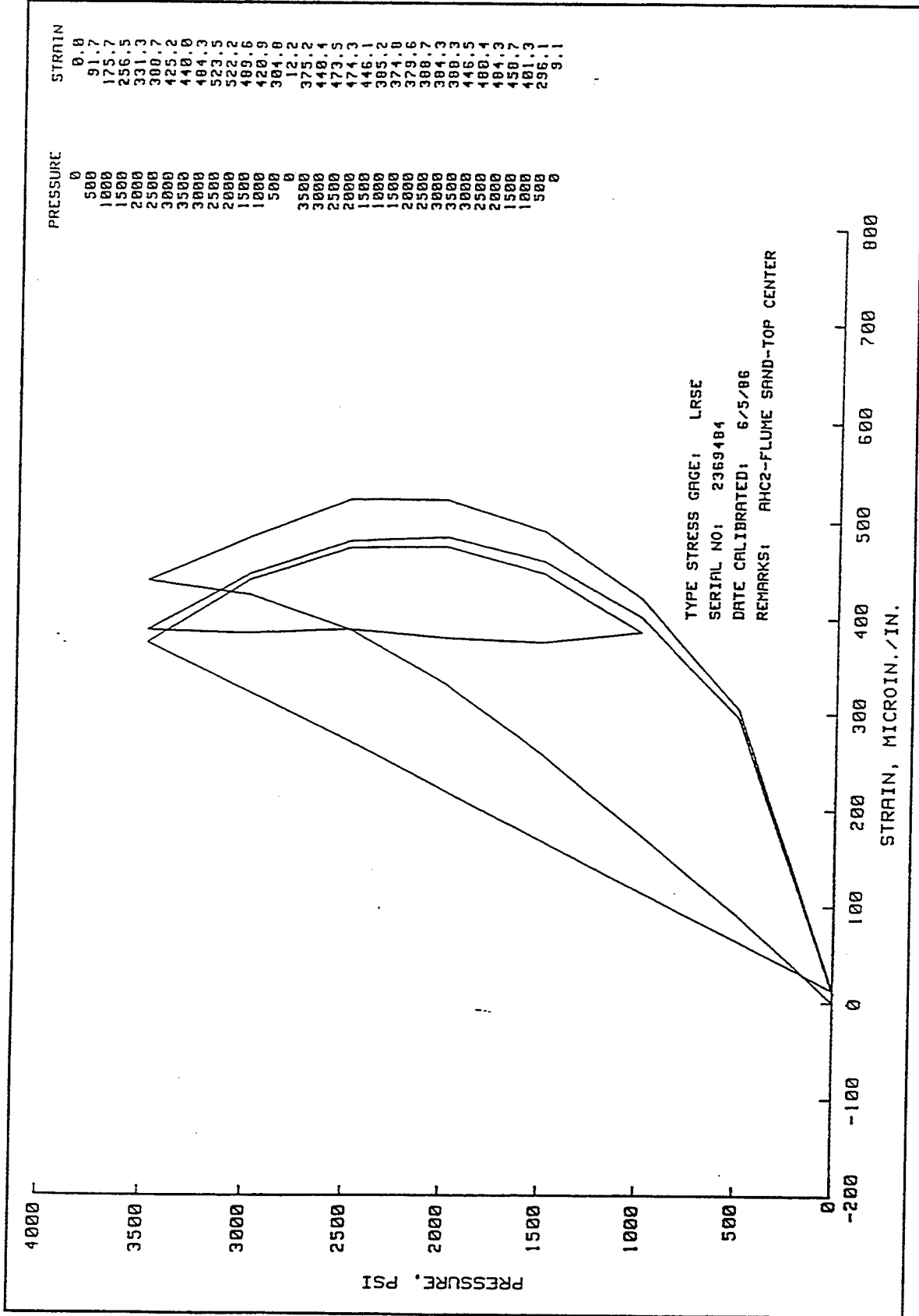
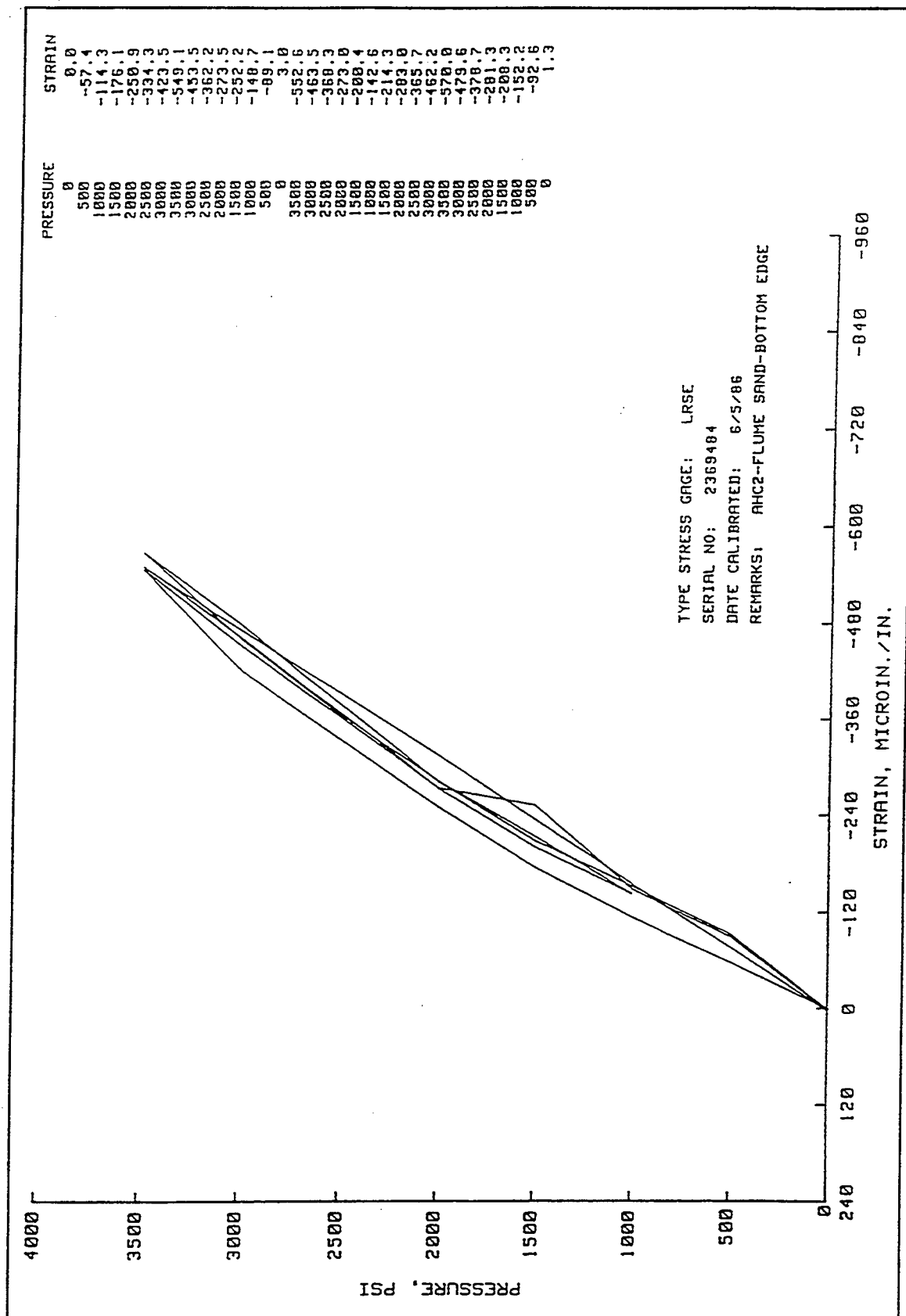
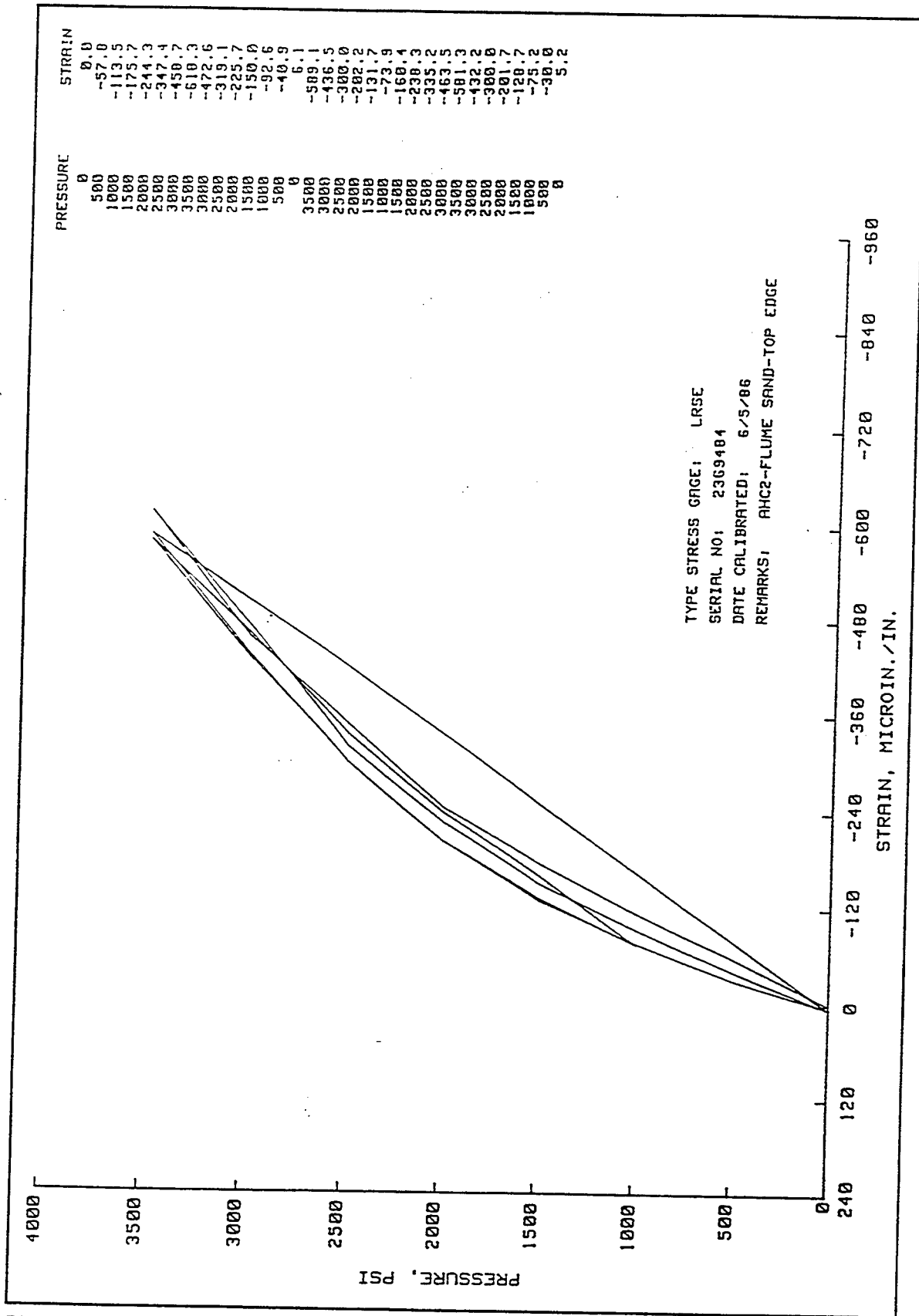
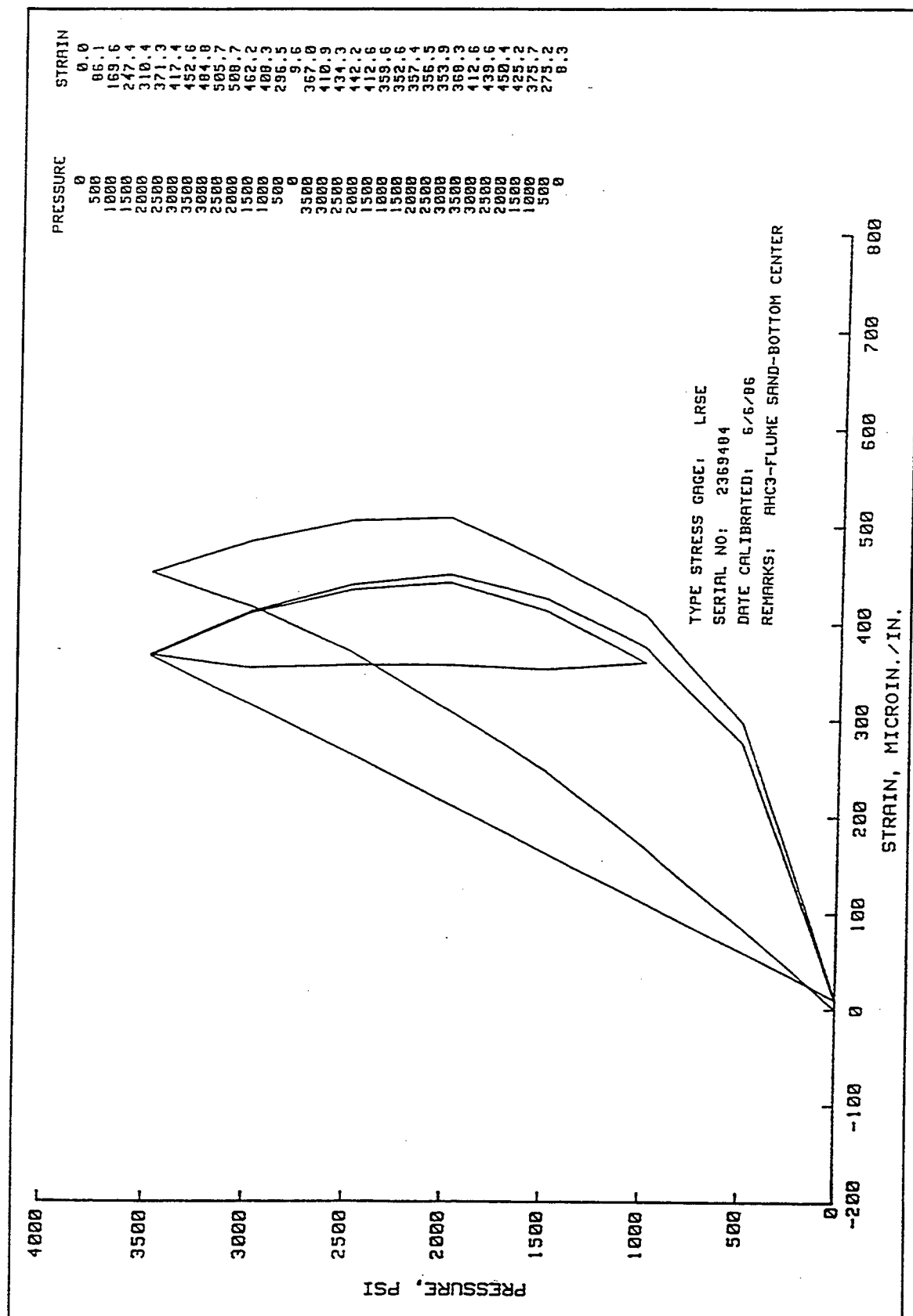


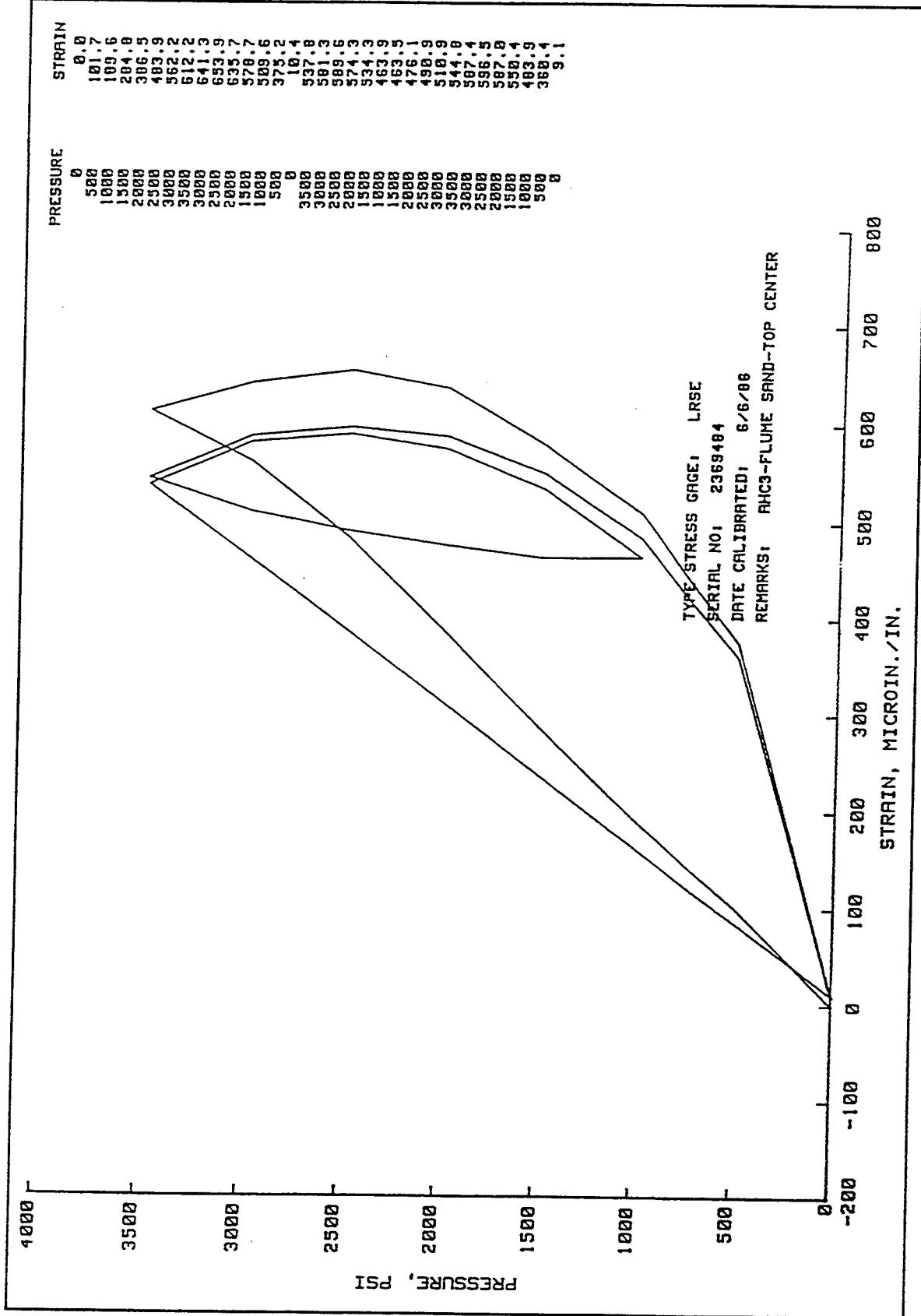
Plate 148

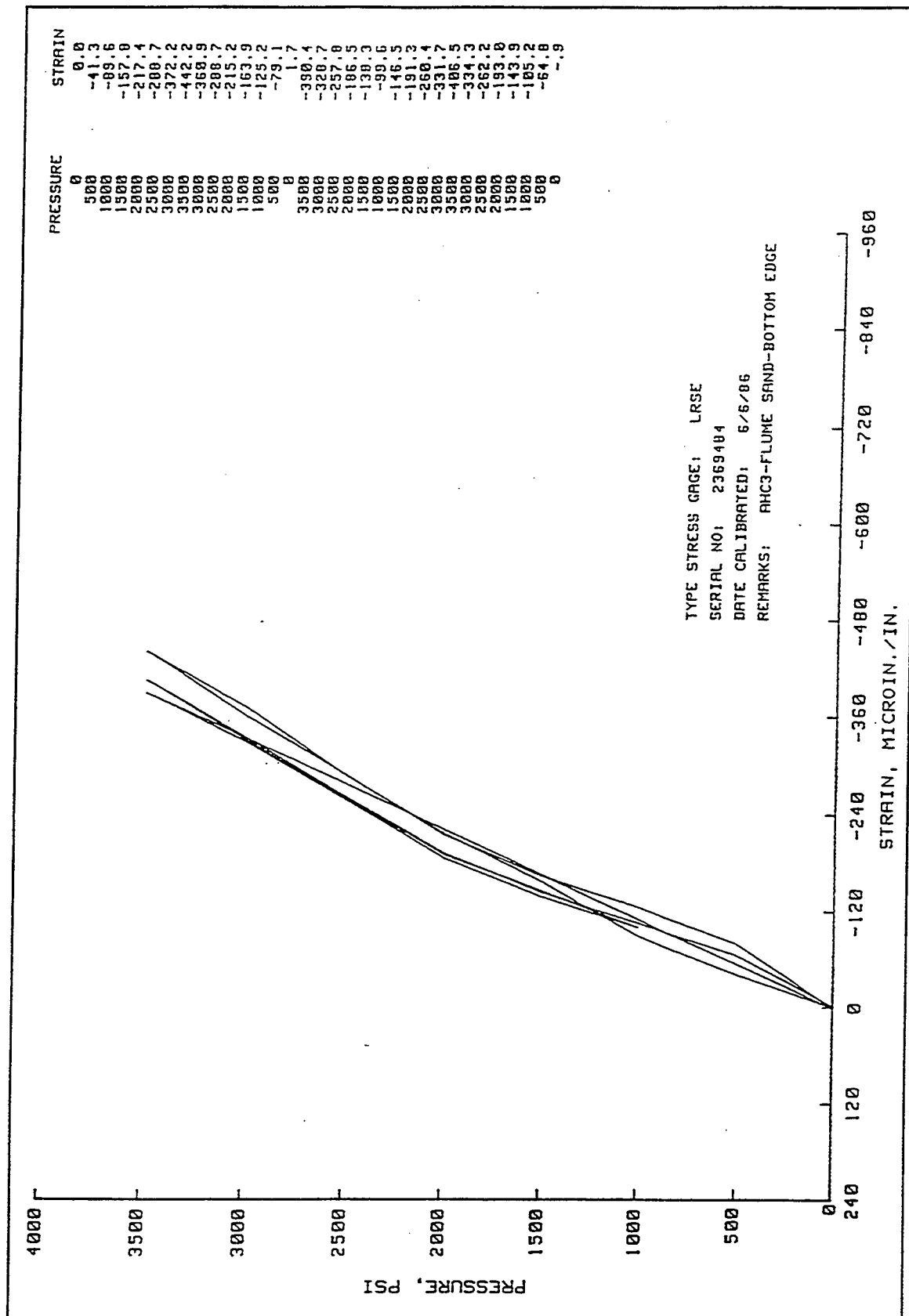


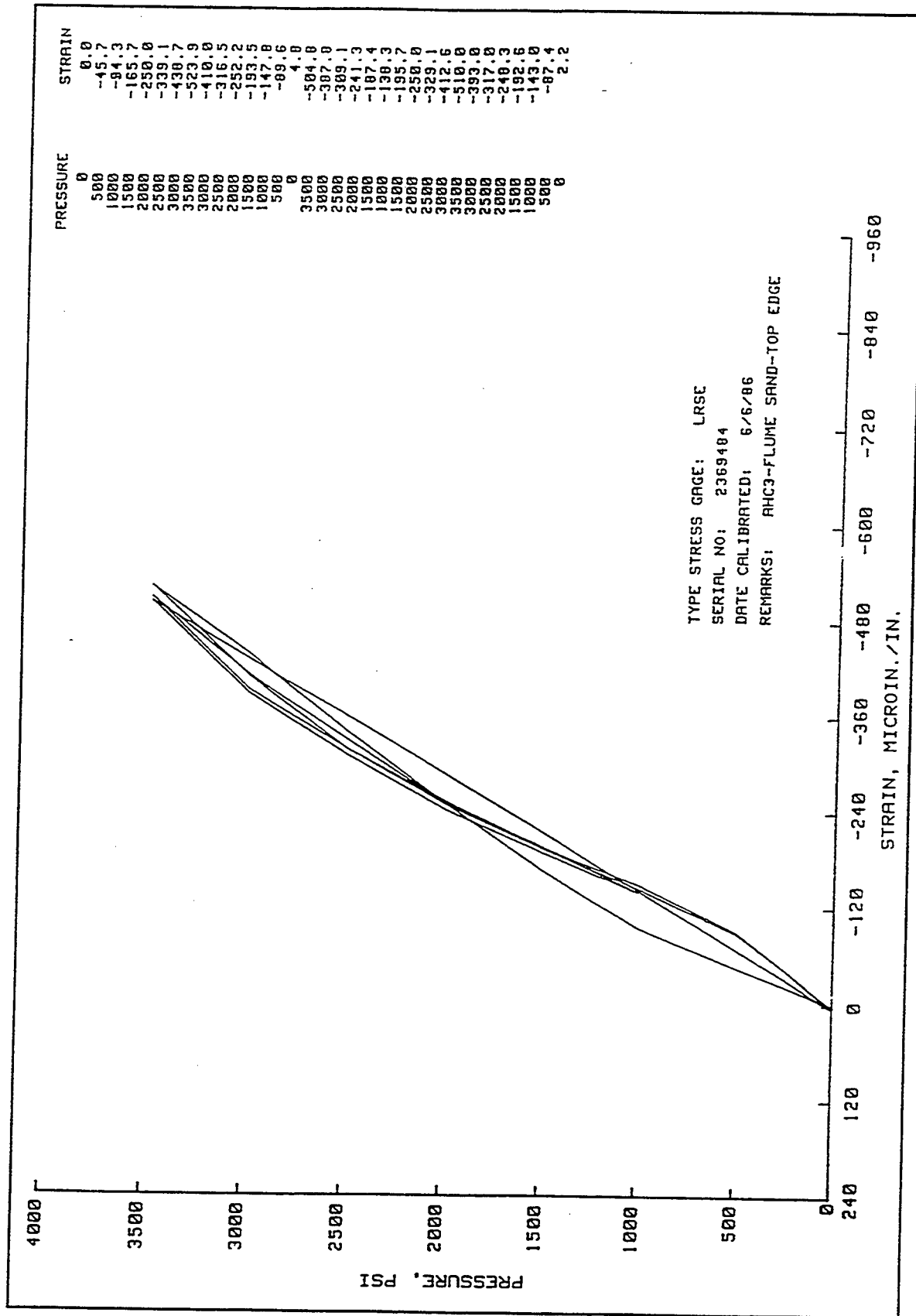


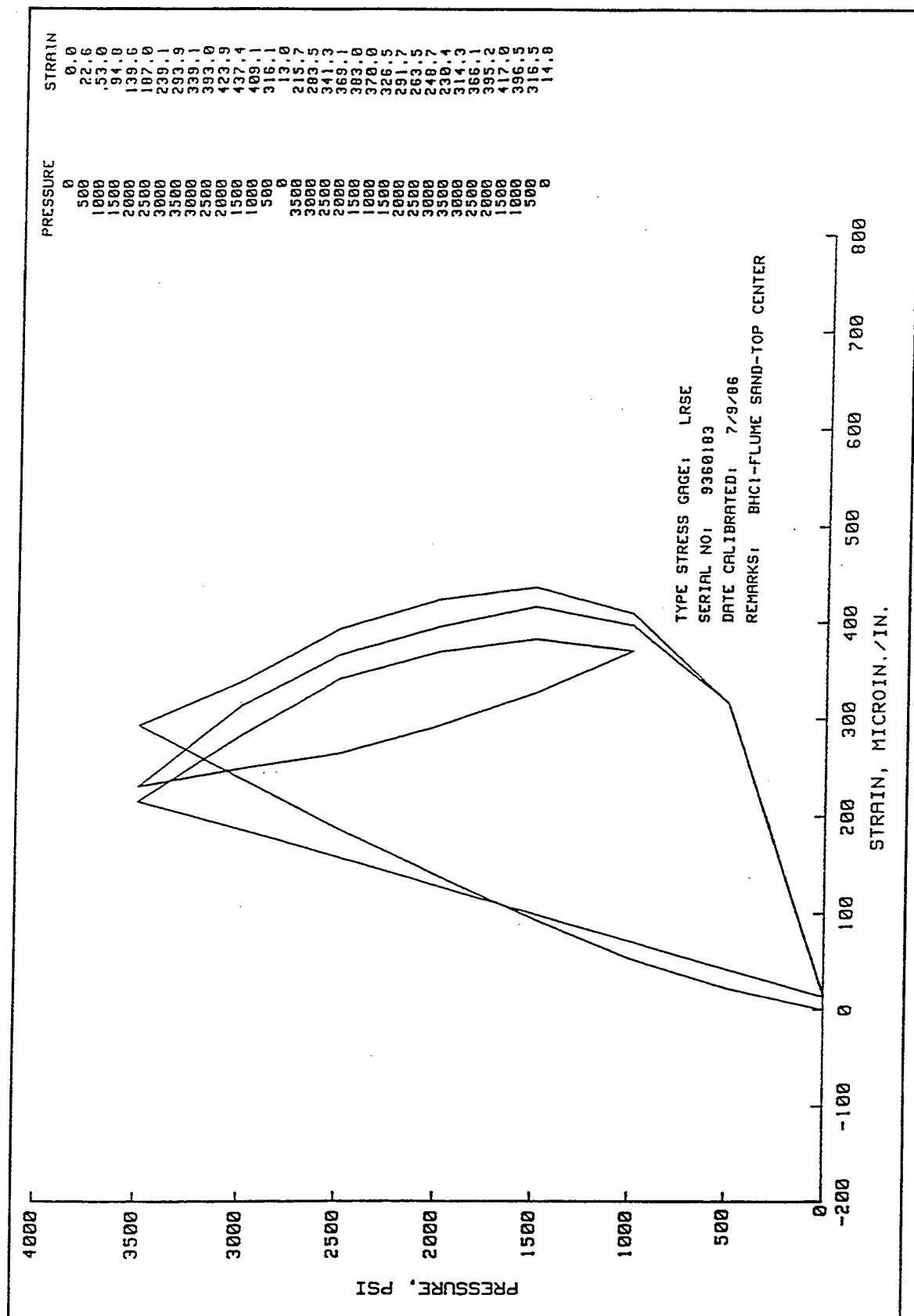


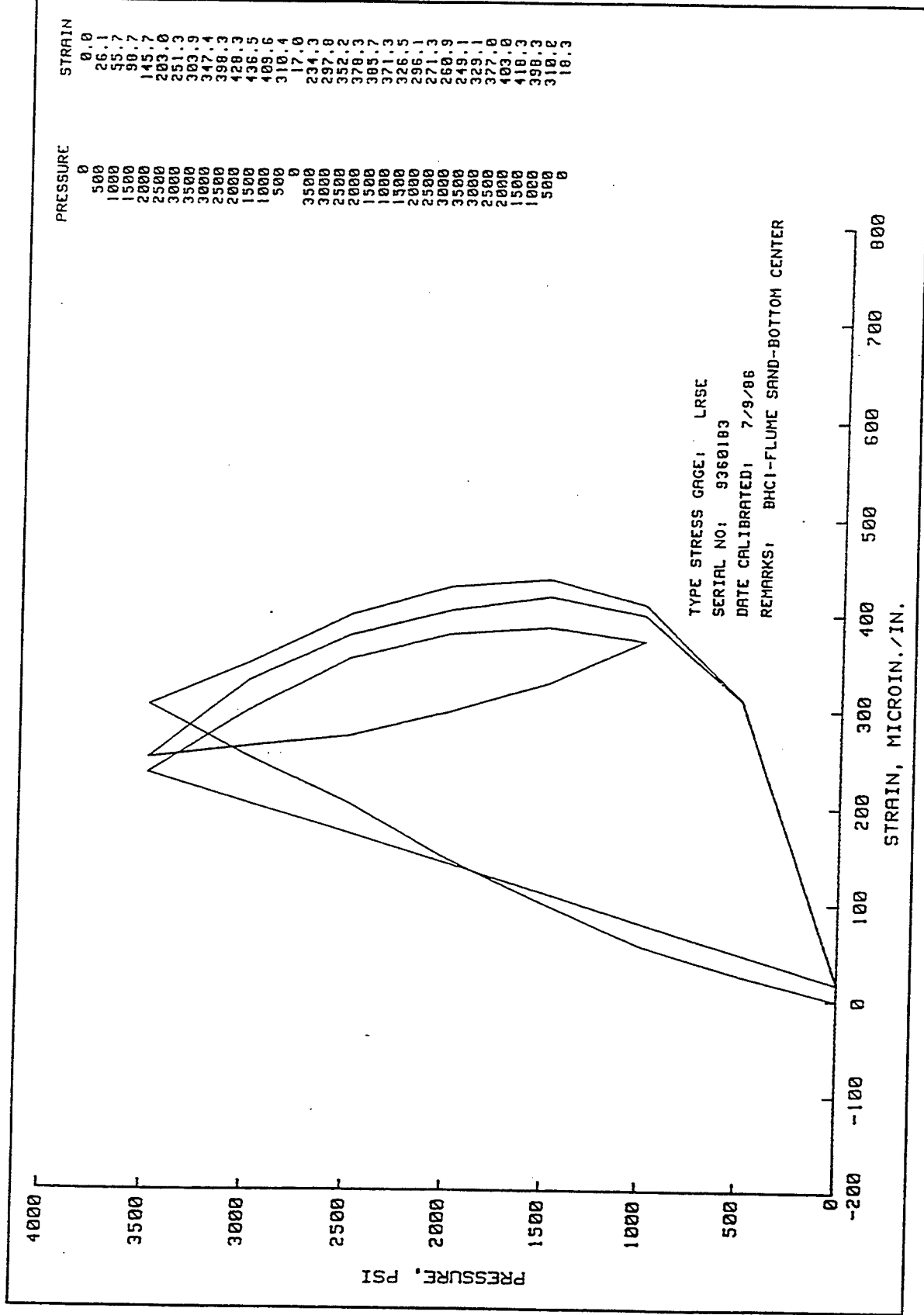


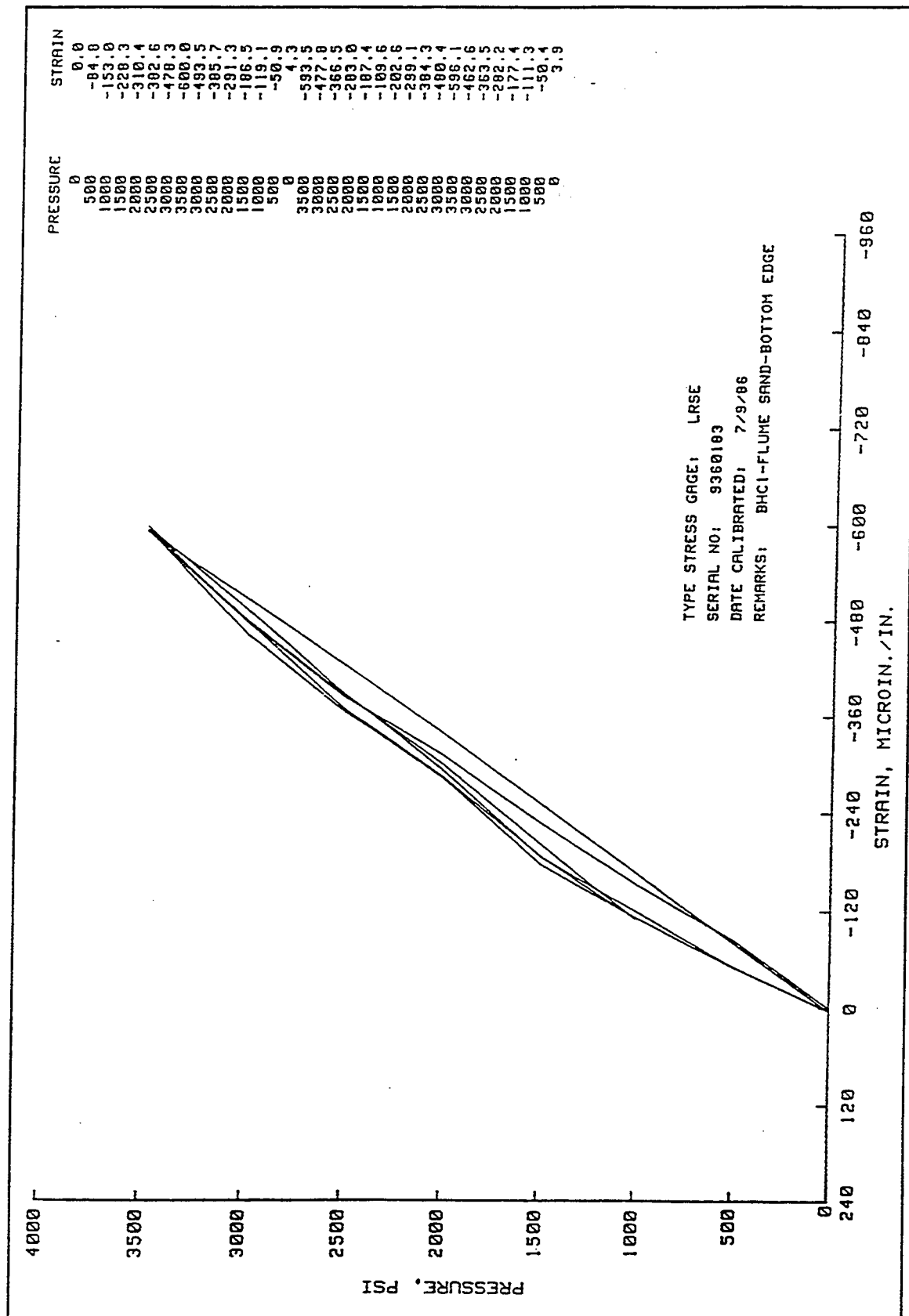


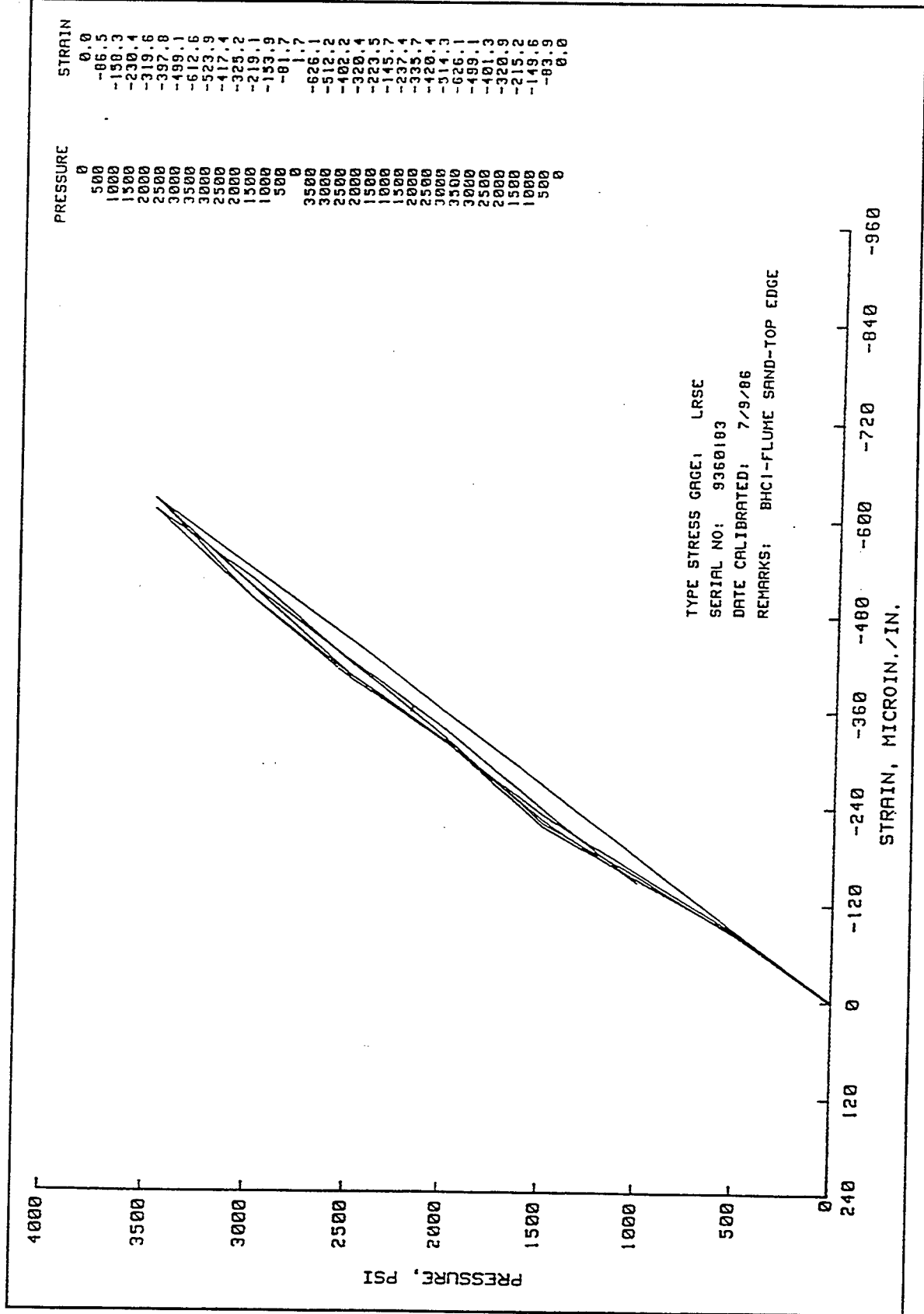


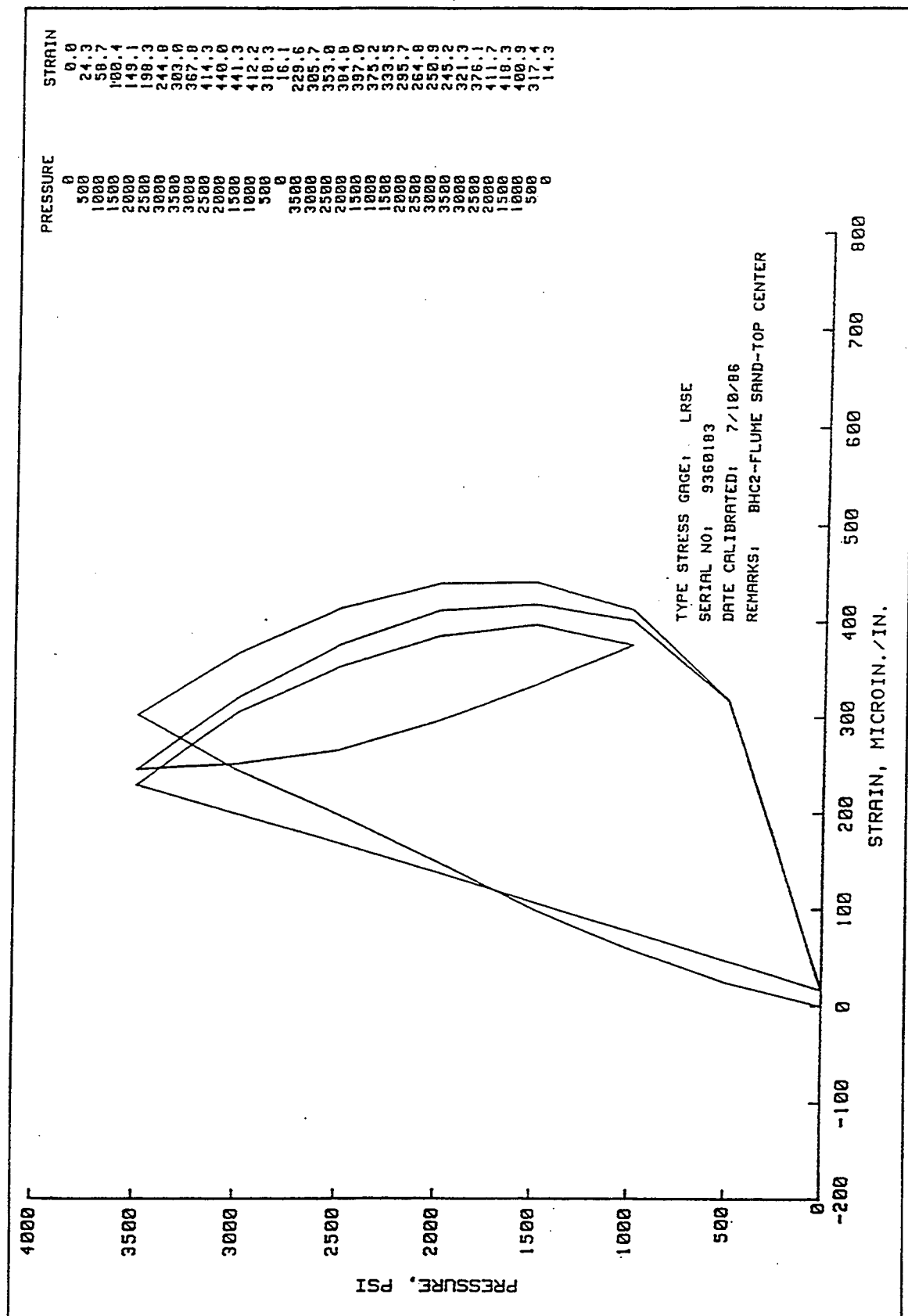




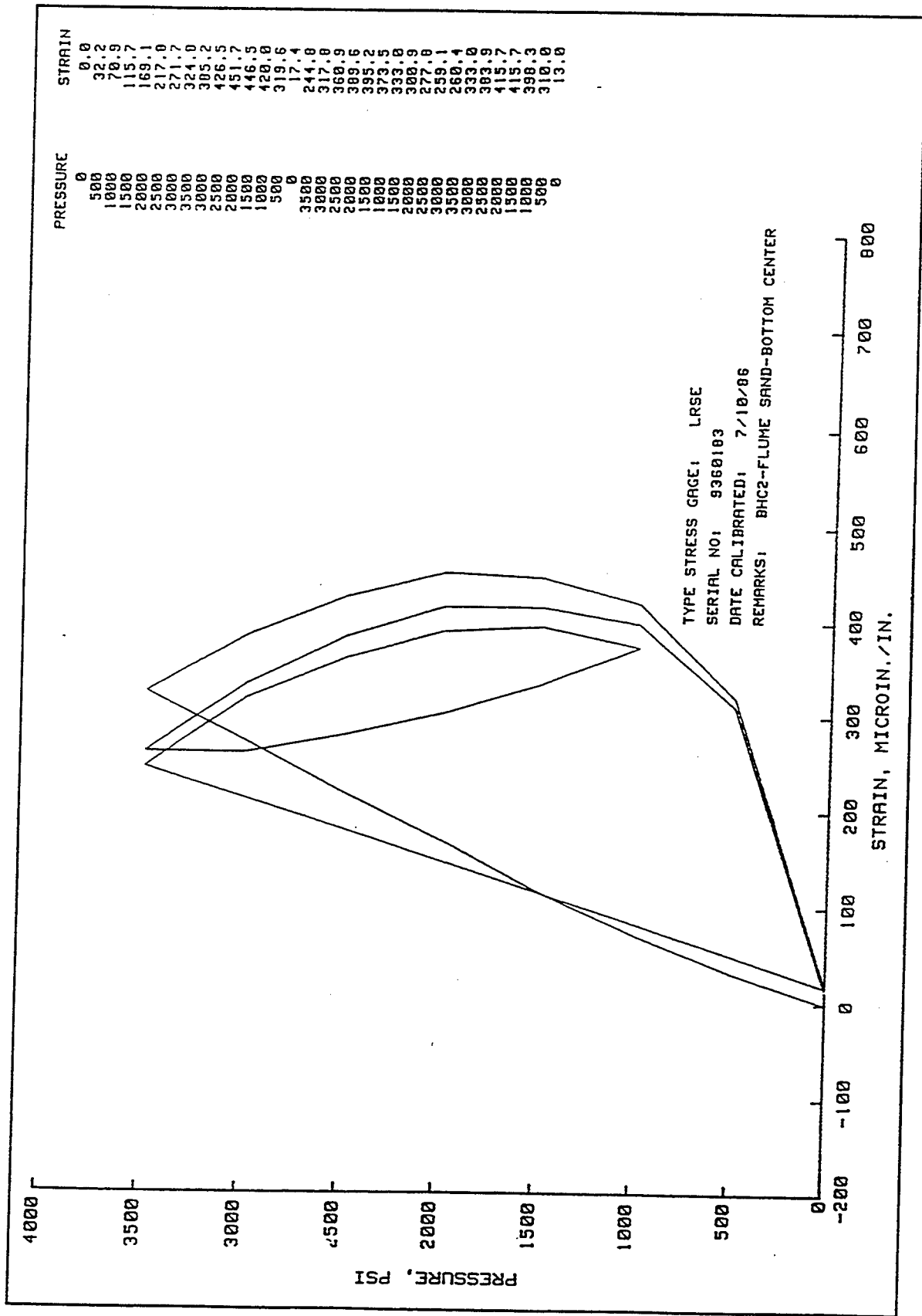


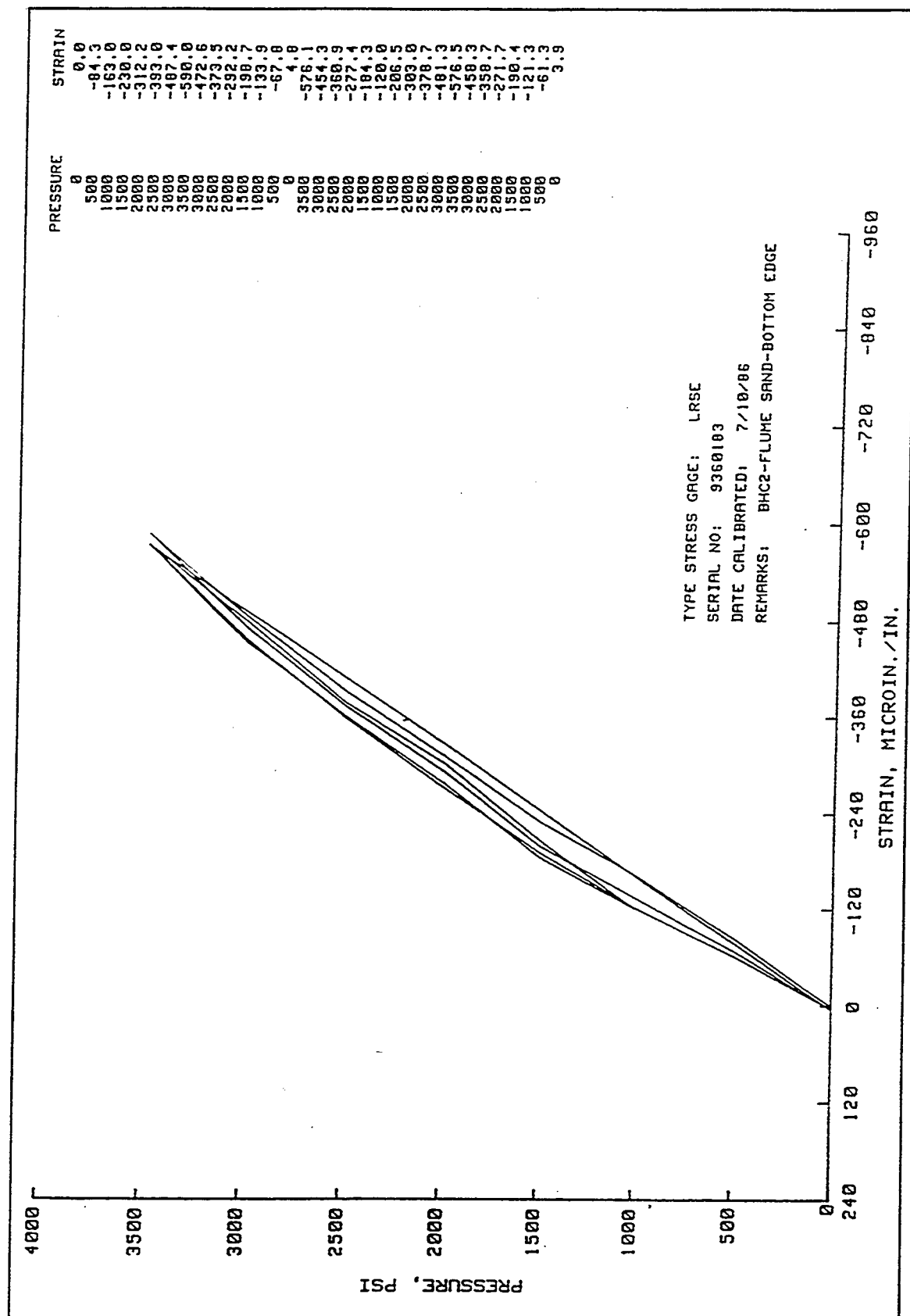


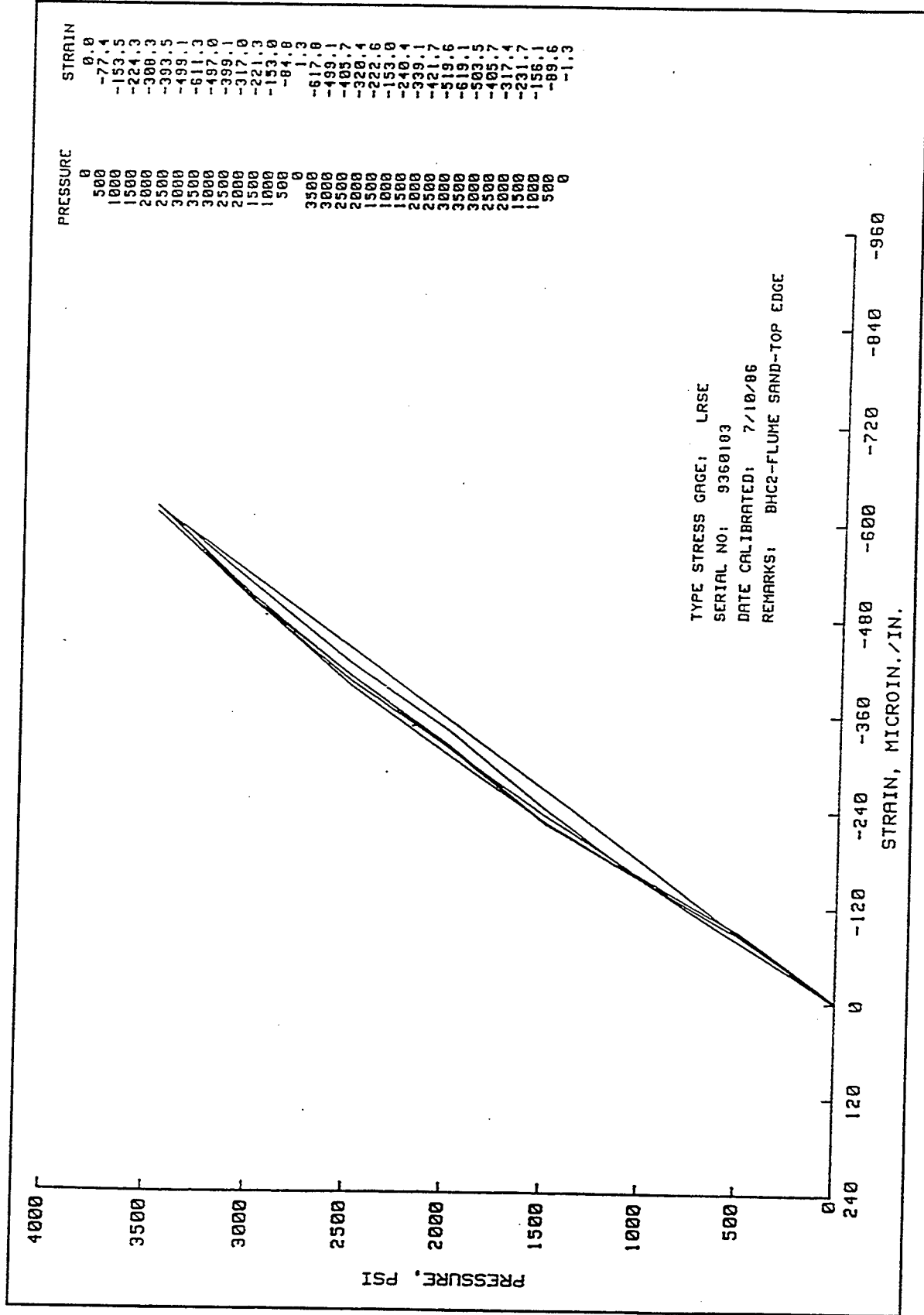


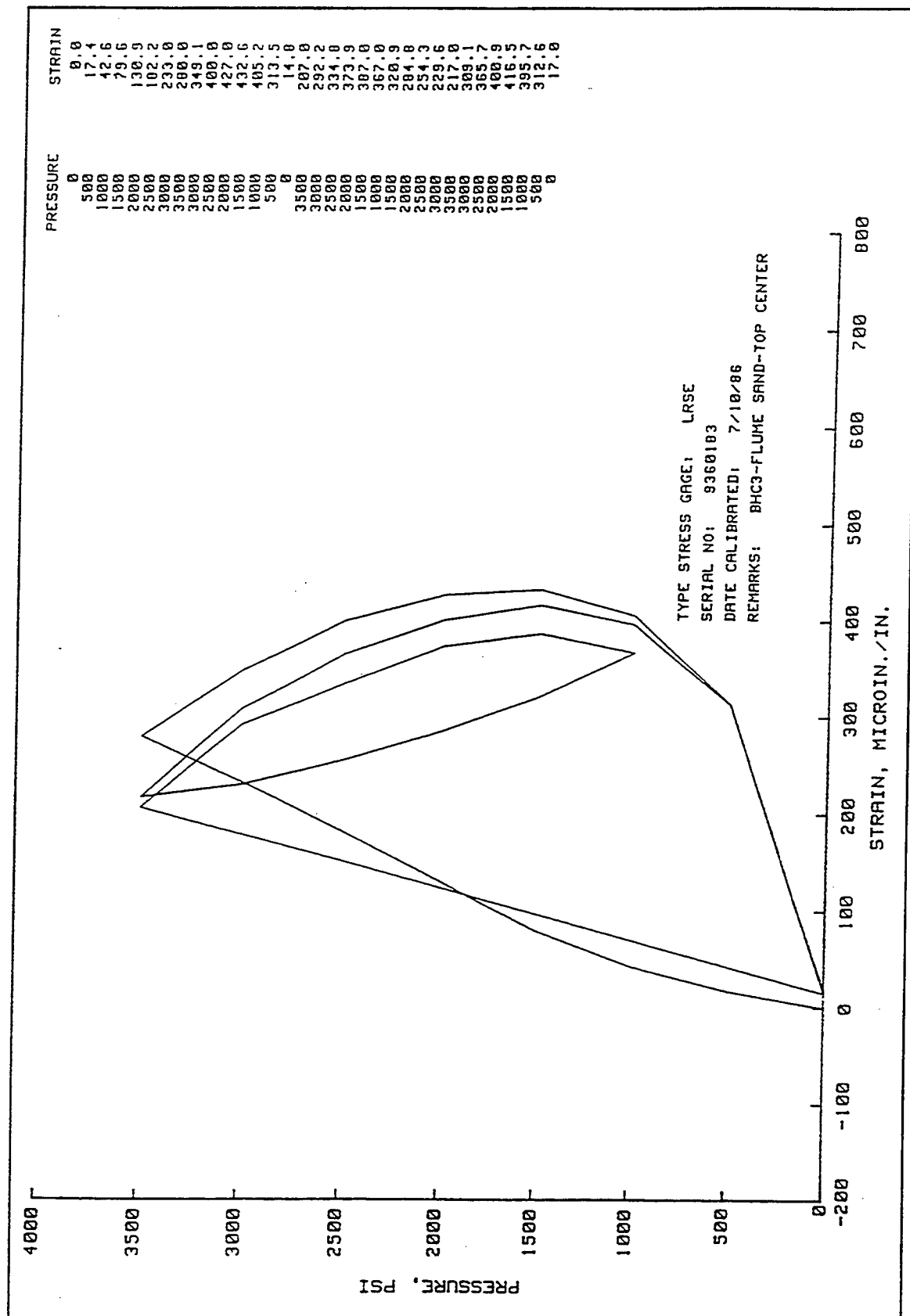


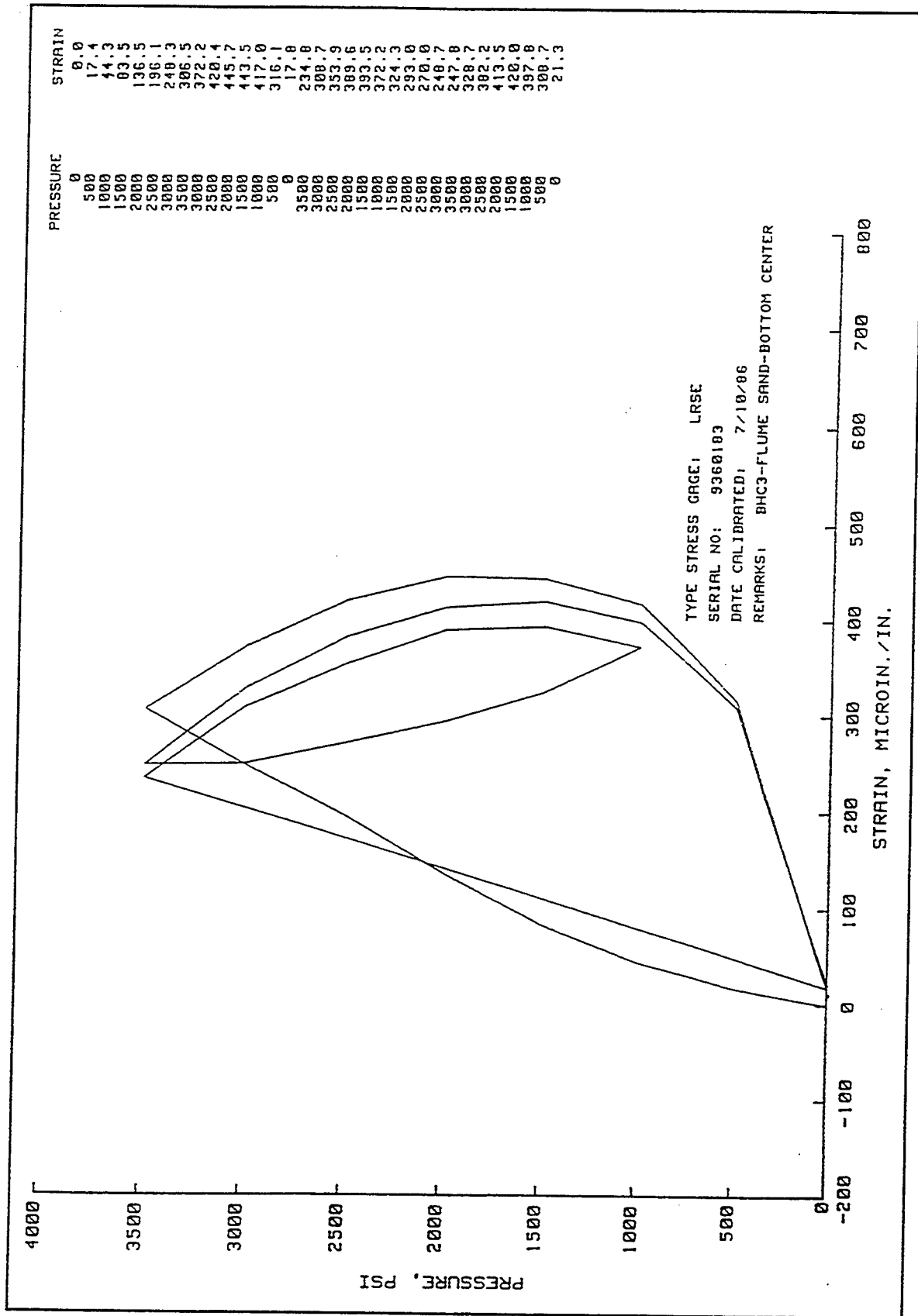


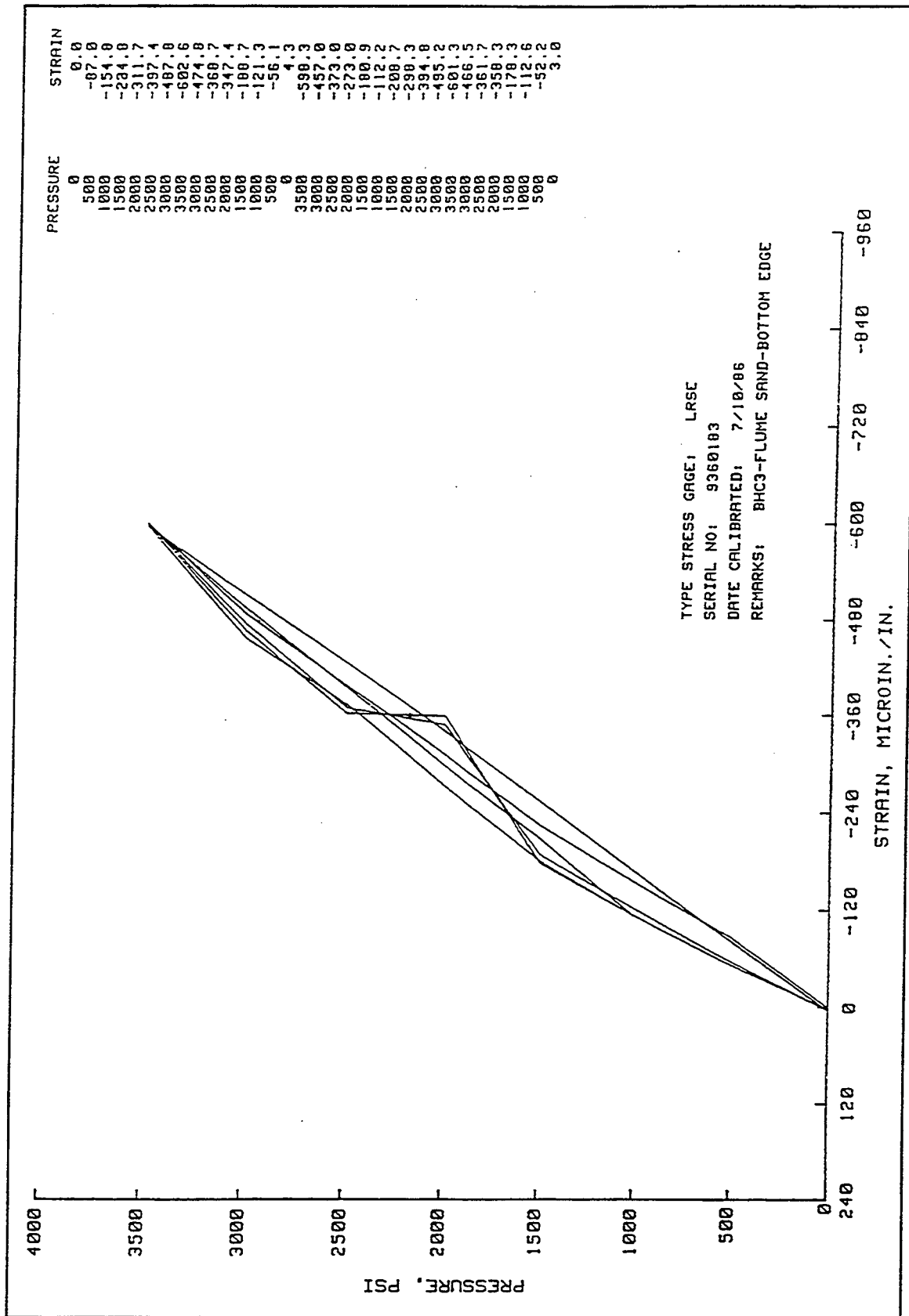


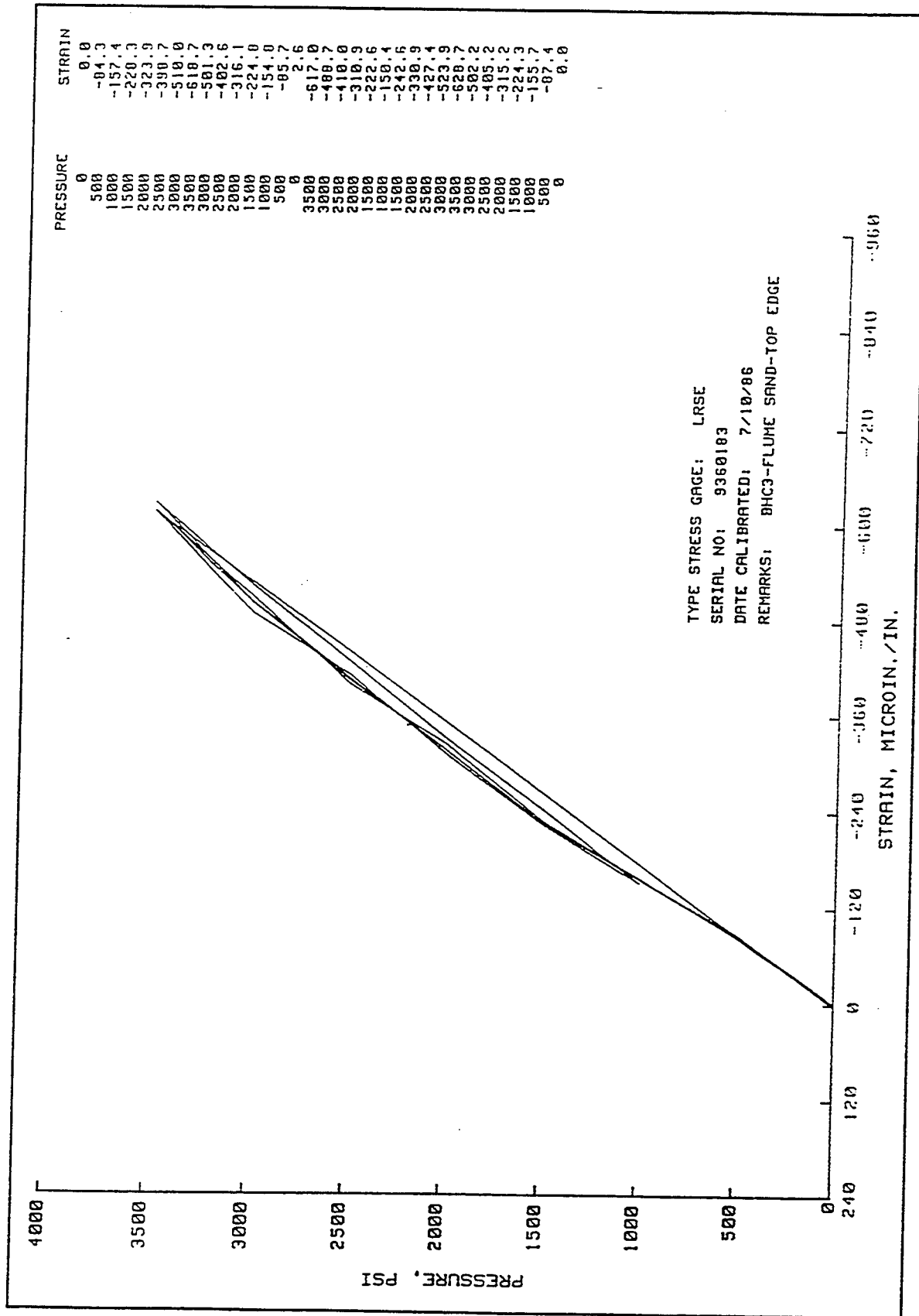


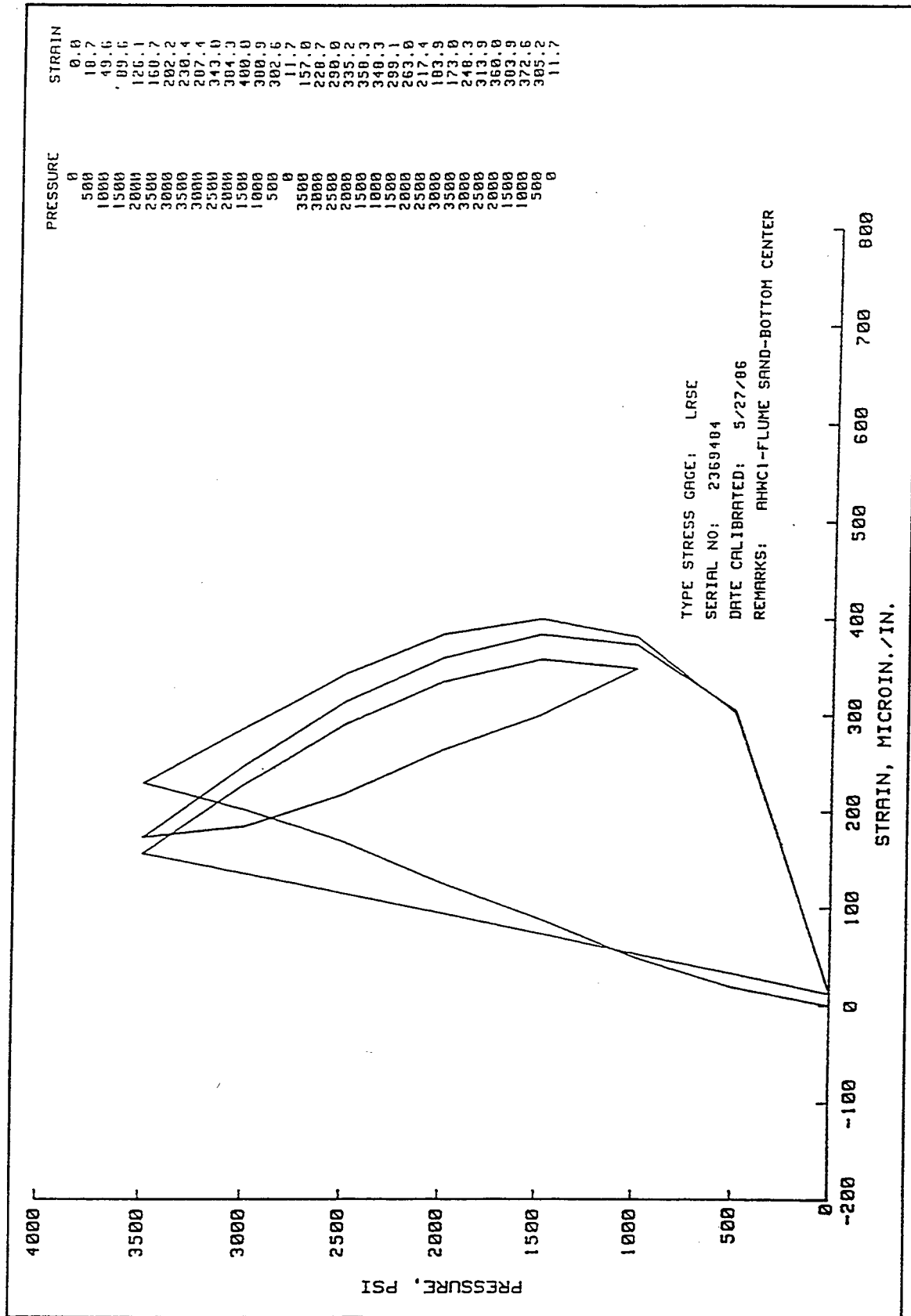




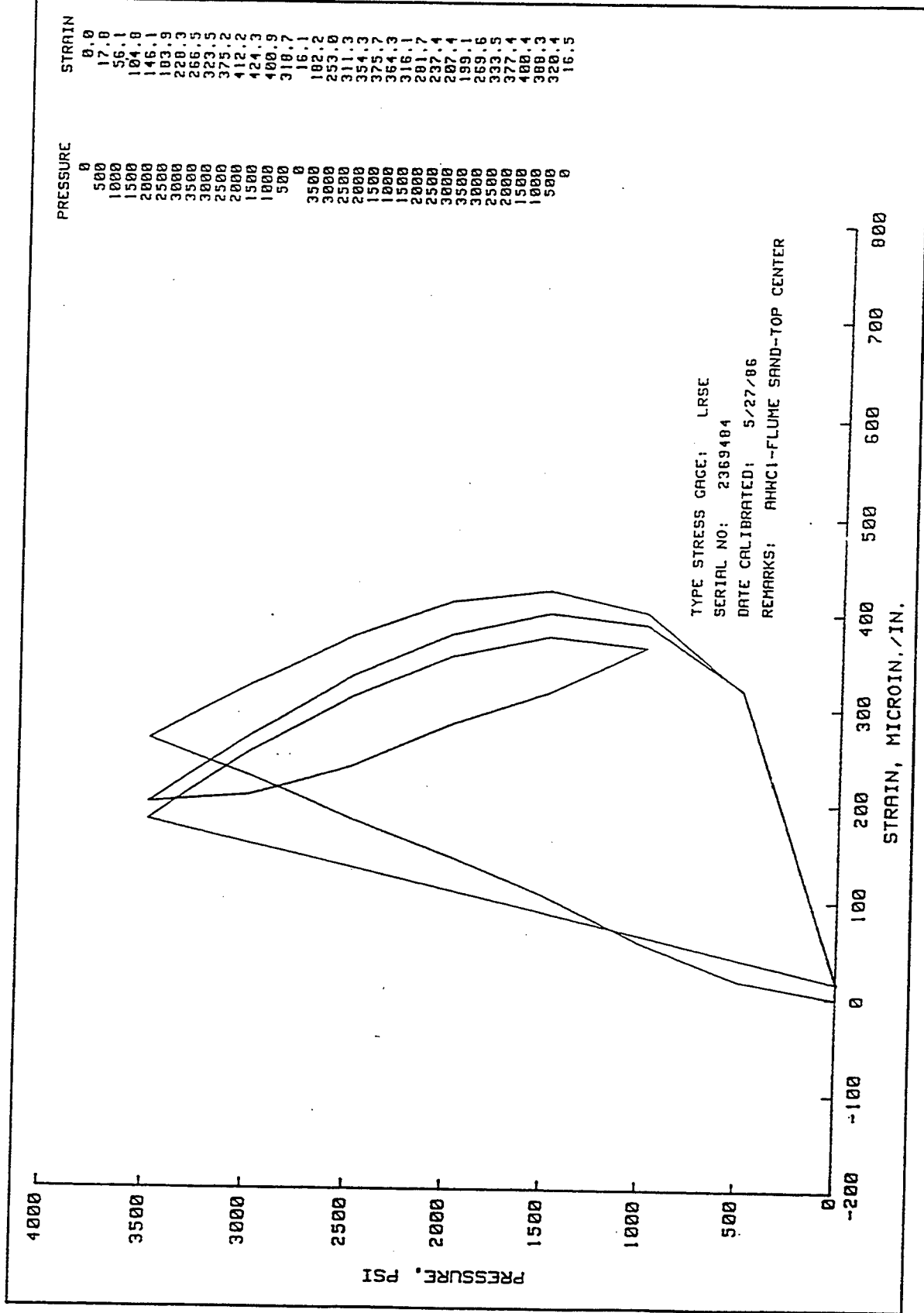


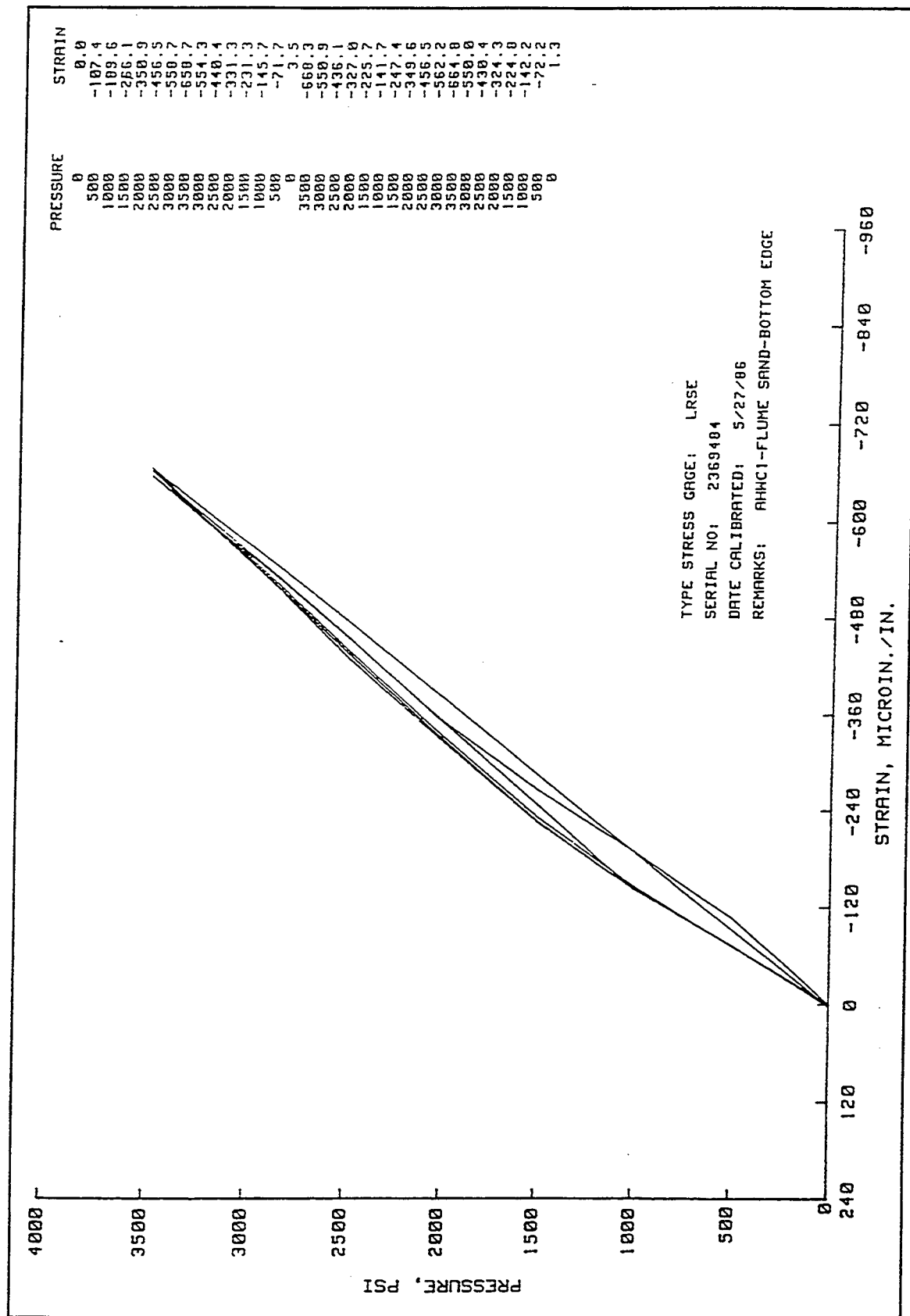


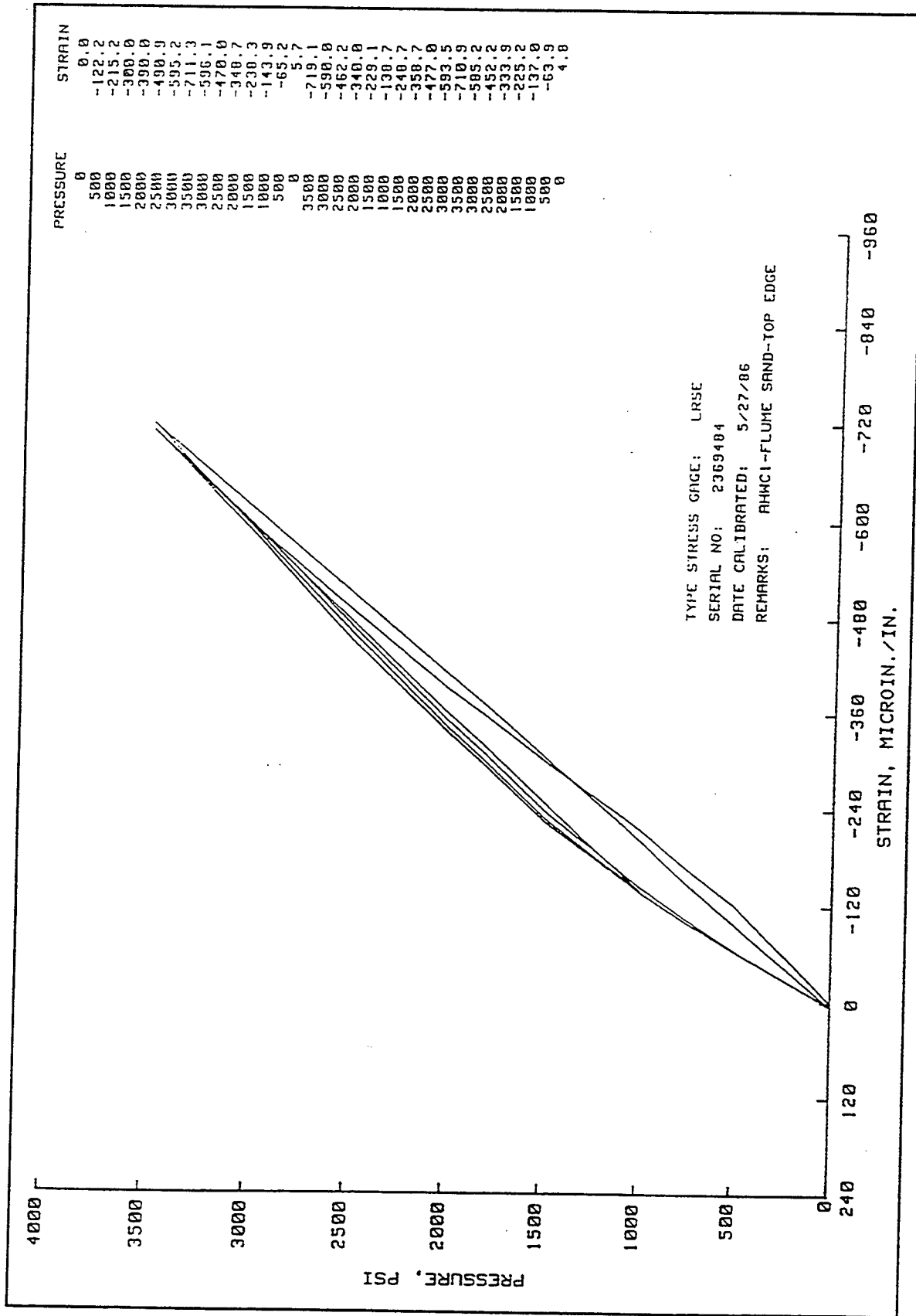


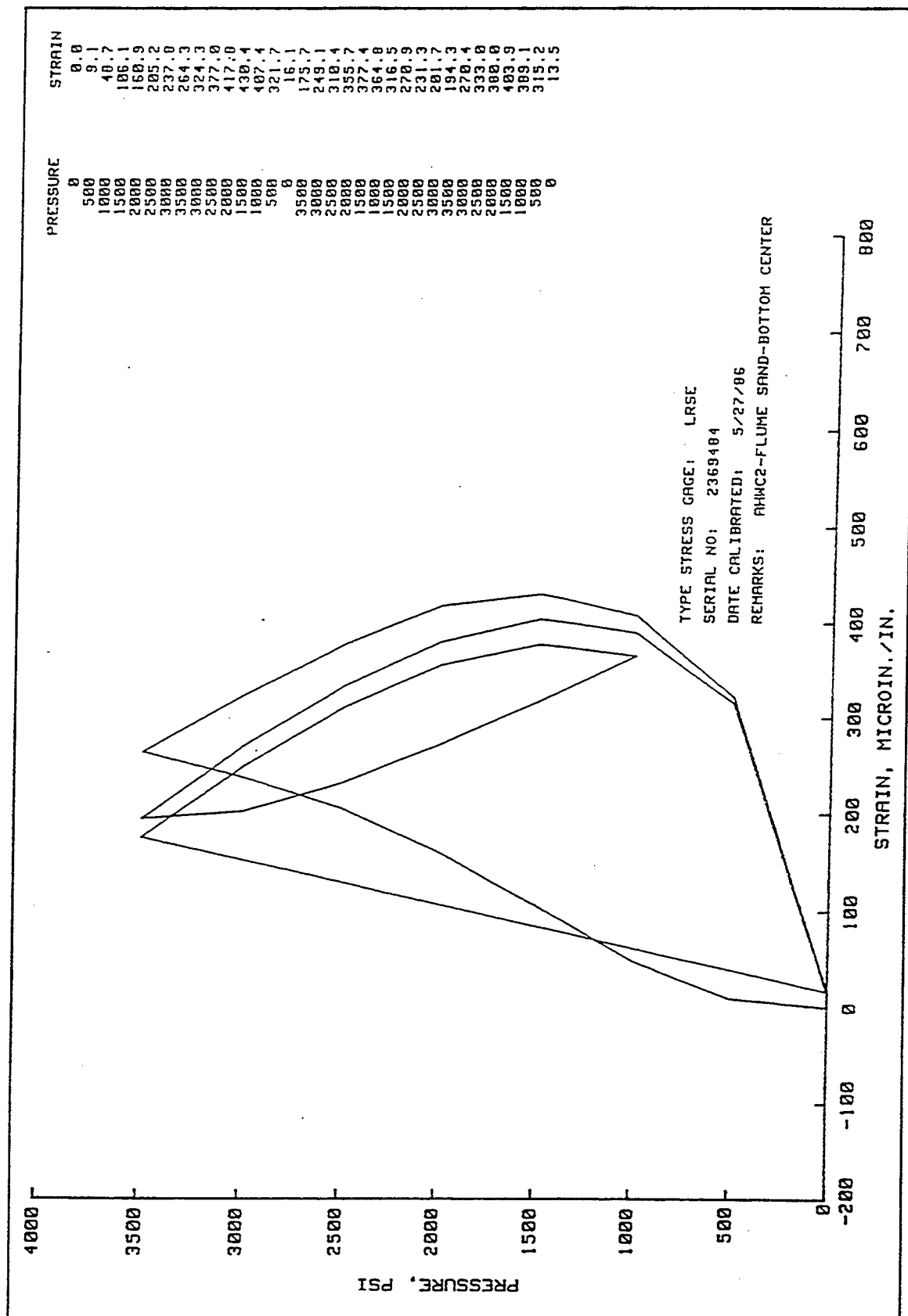


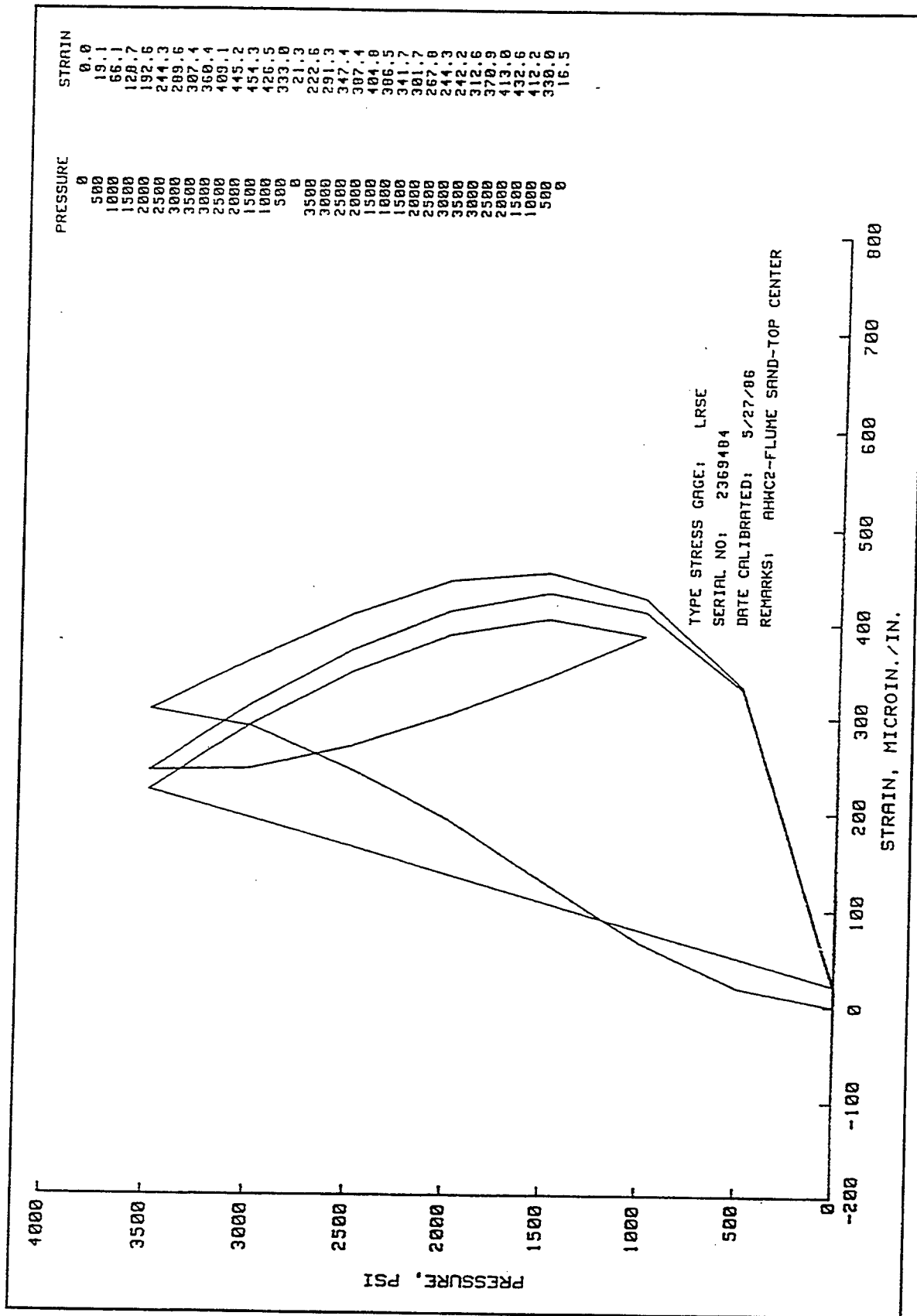


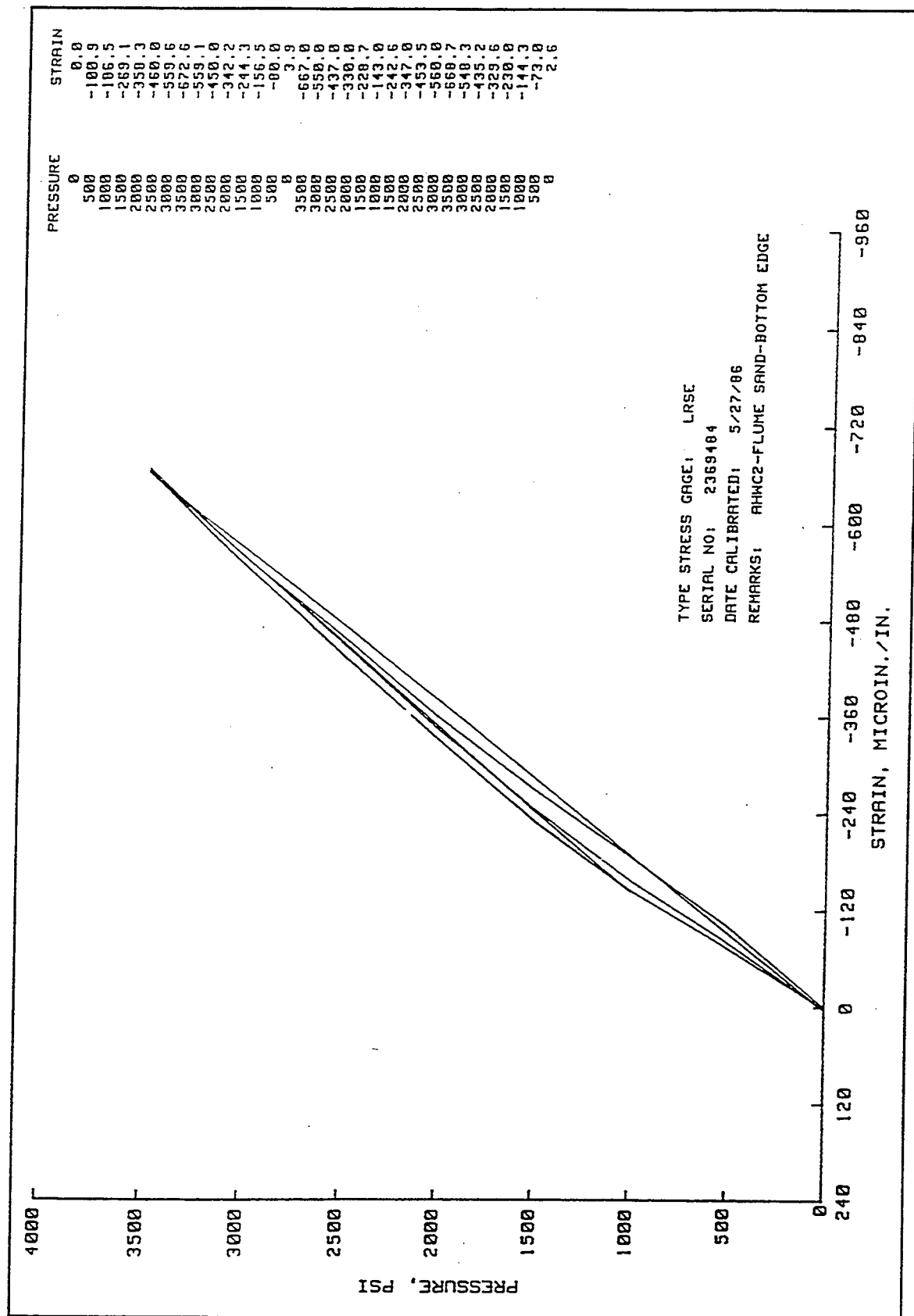


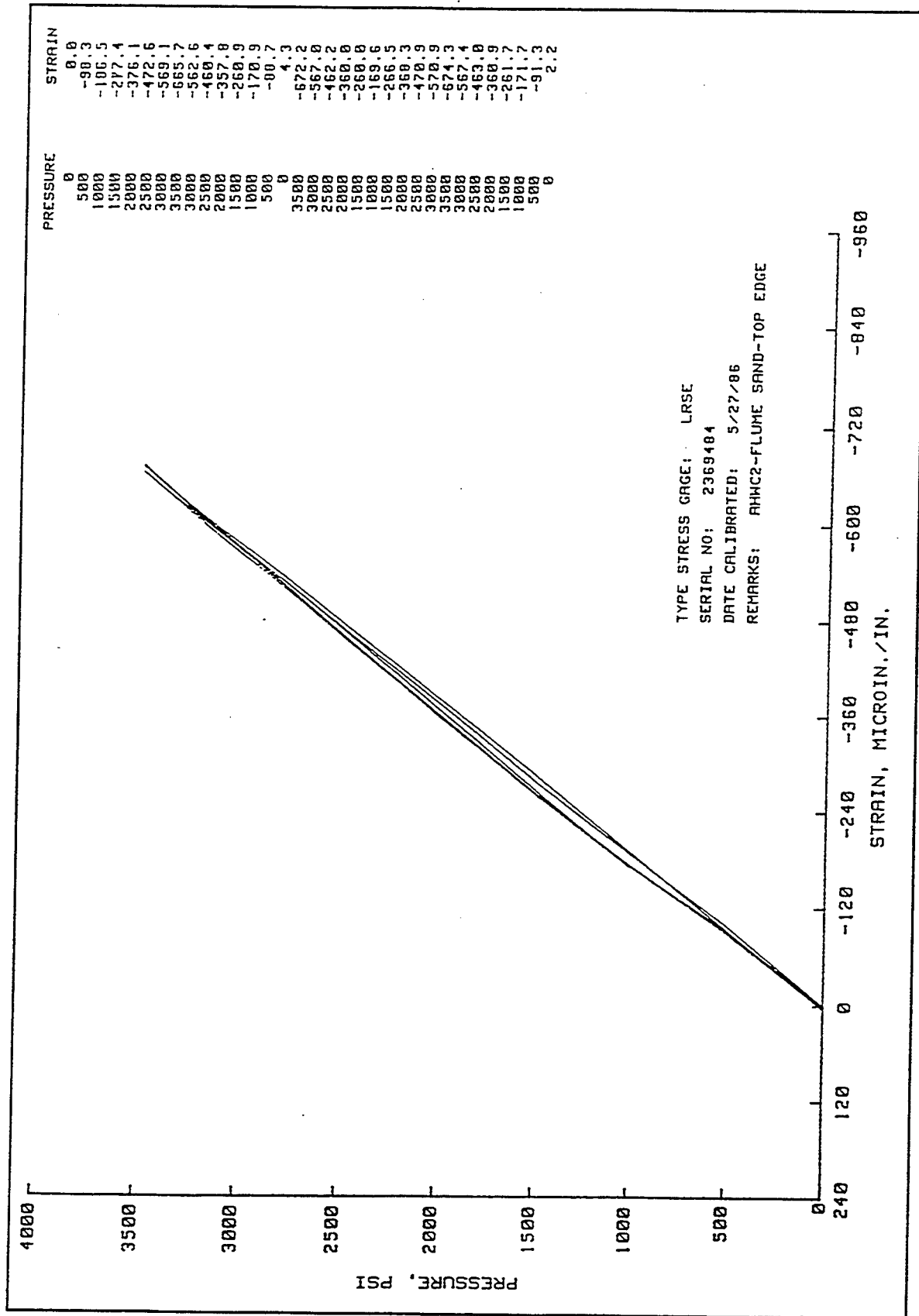


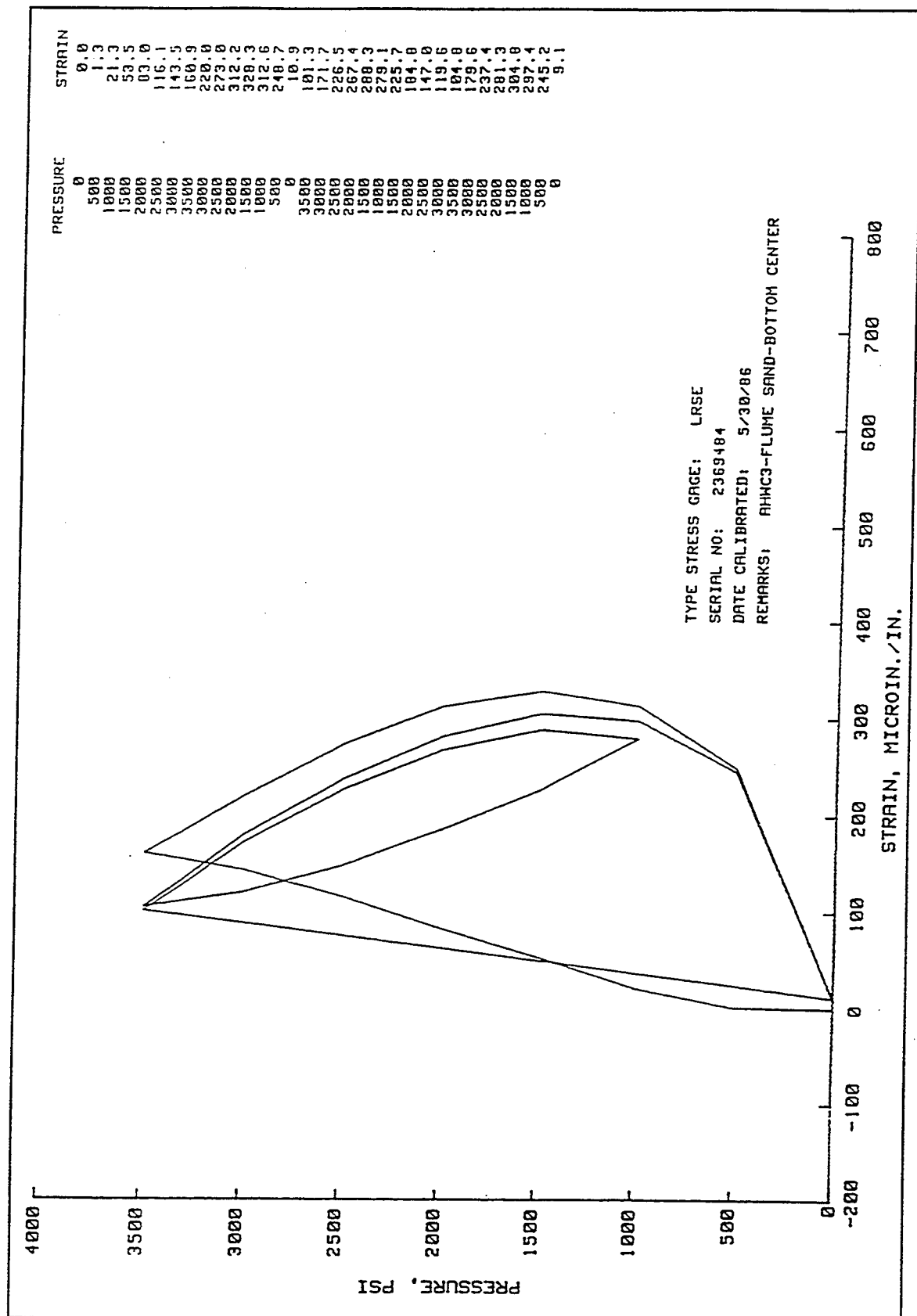




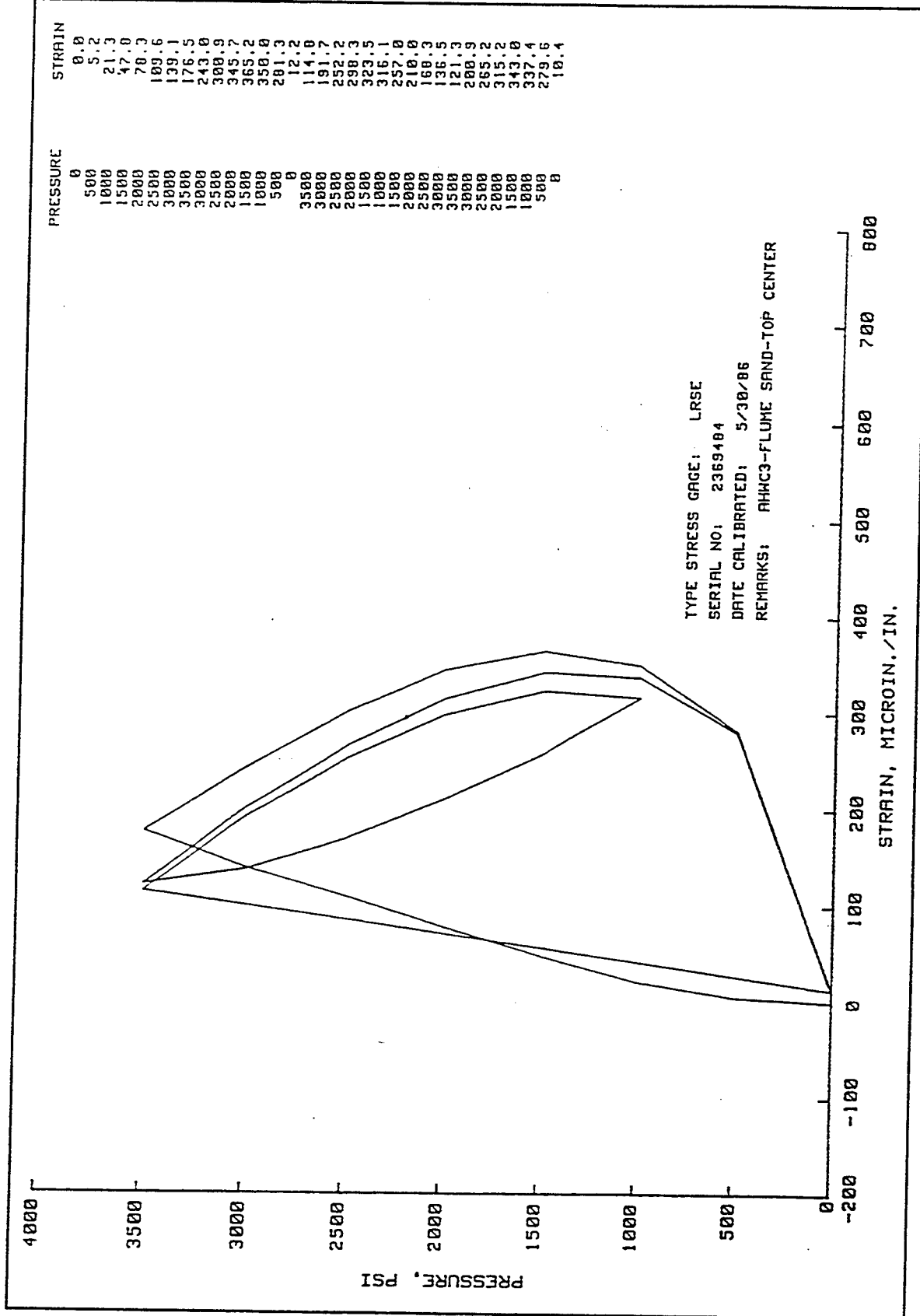


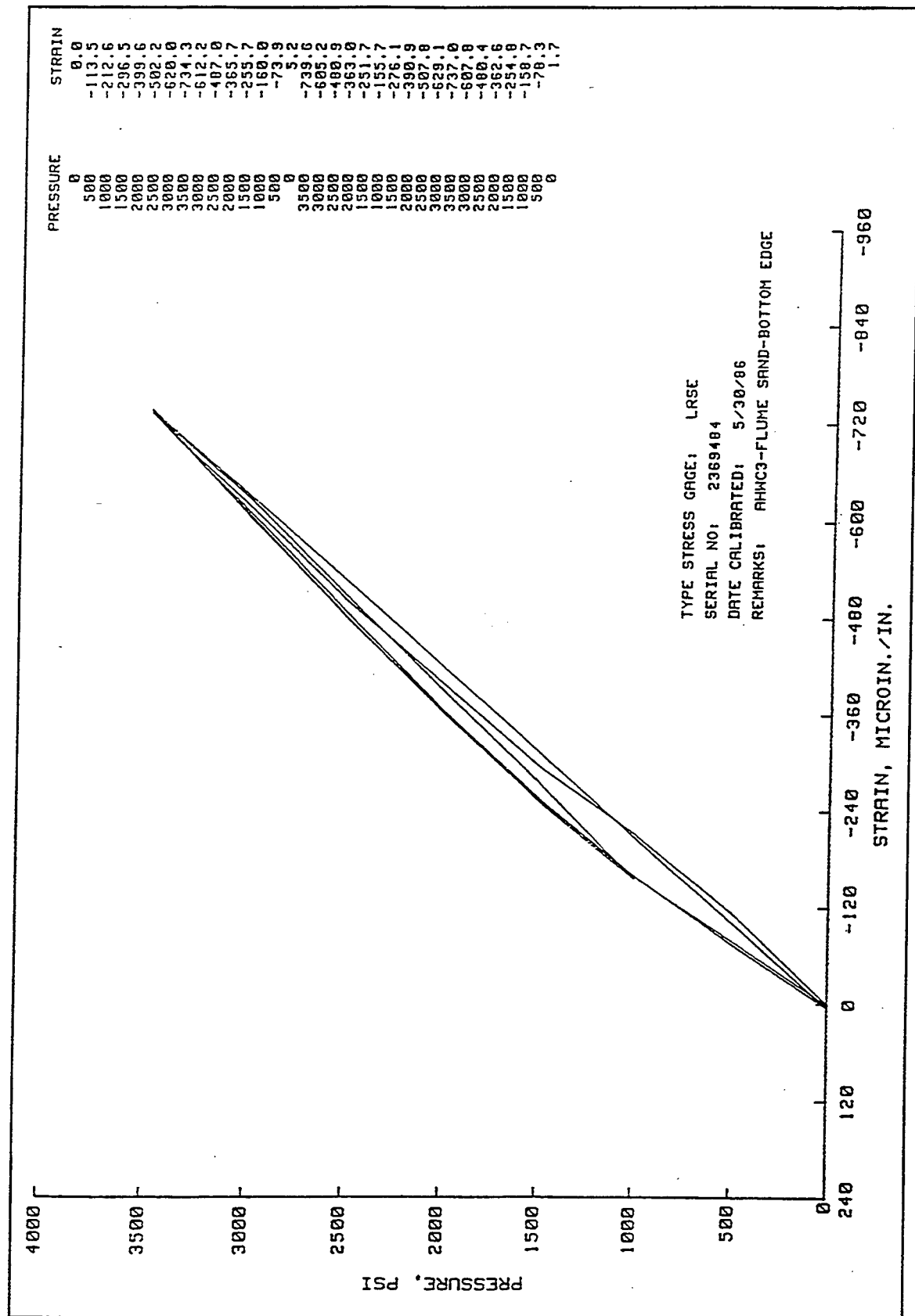


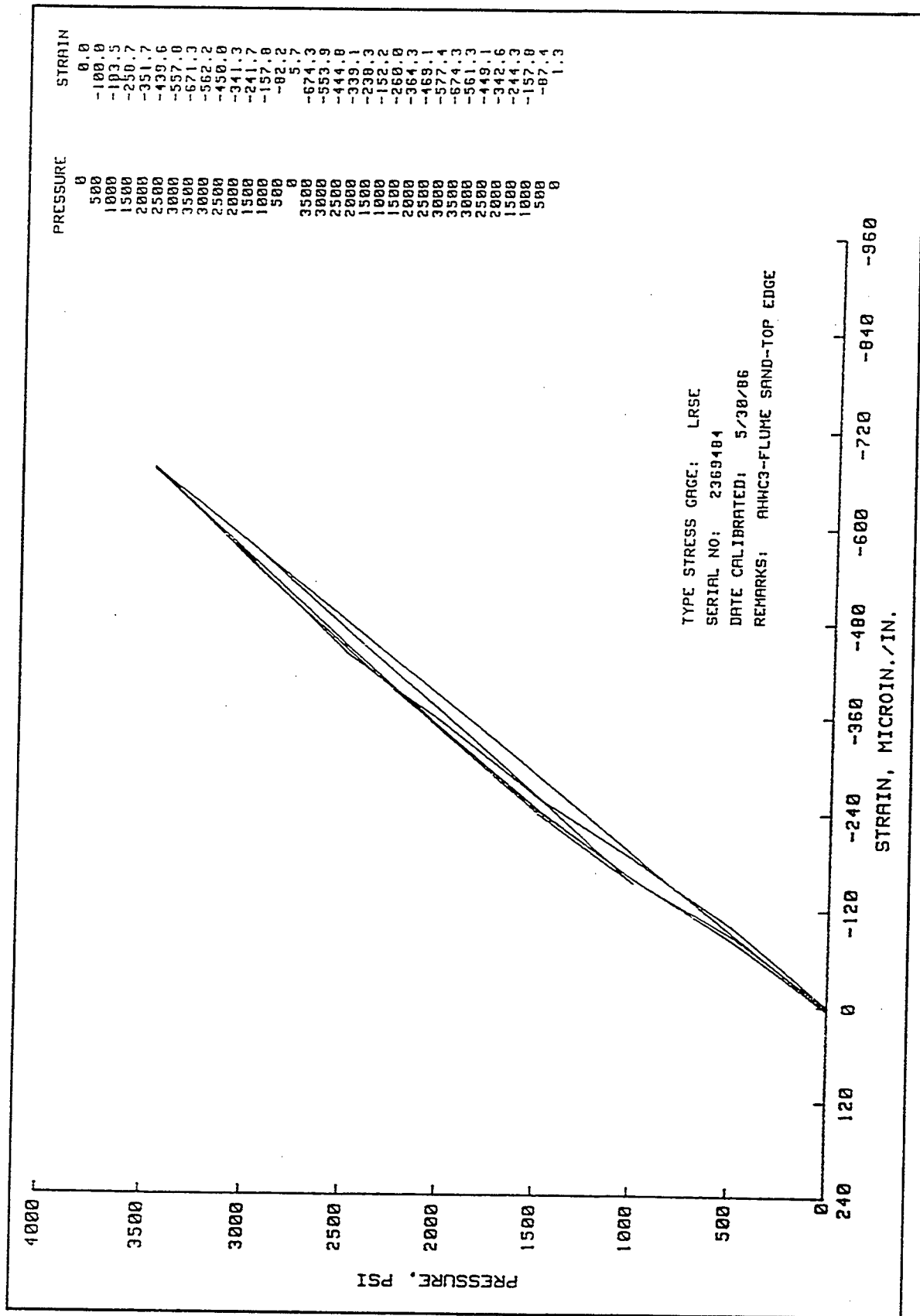


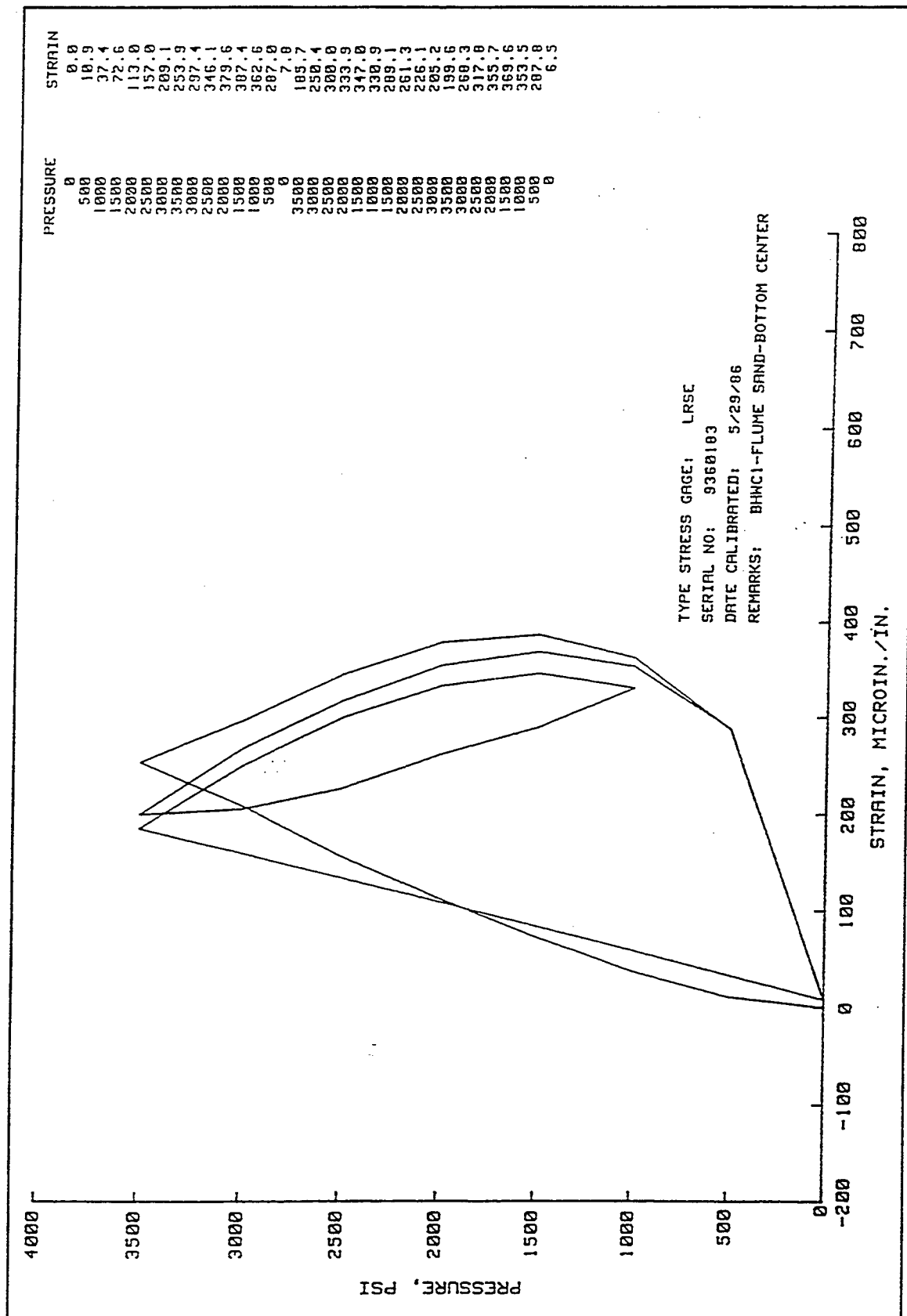


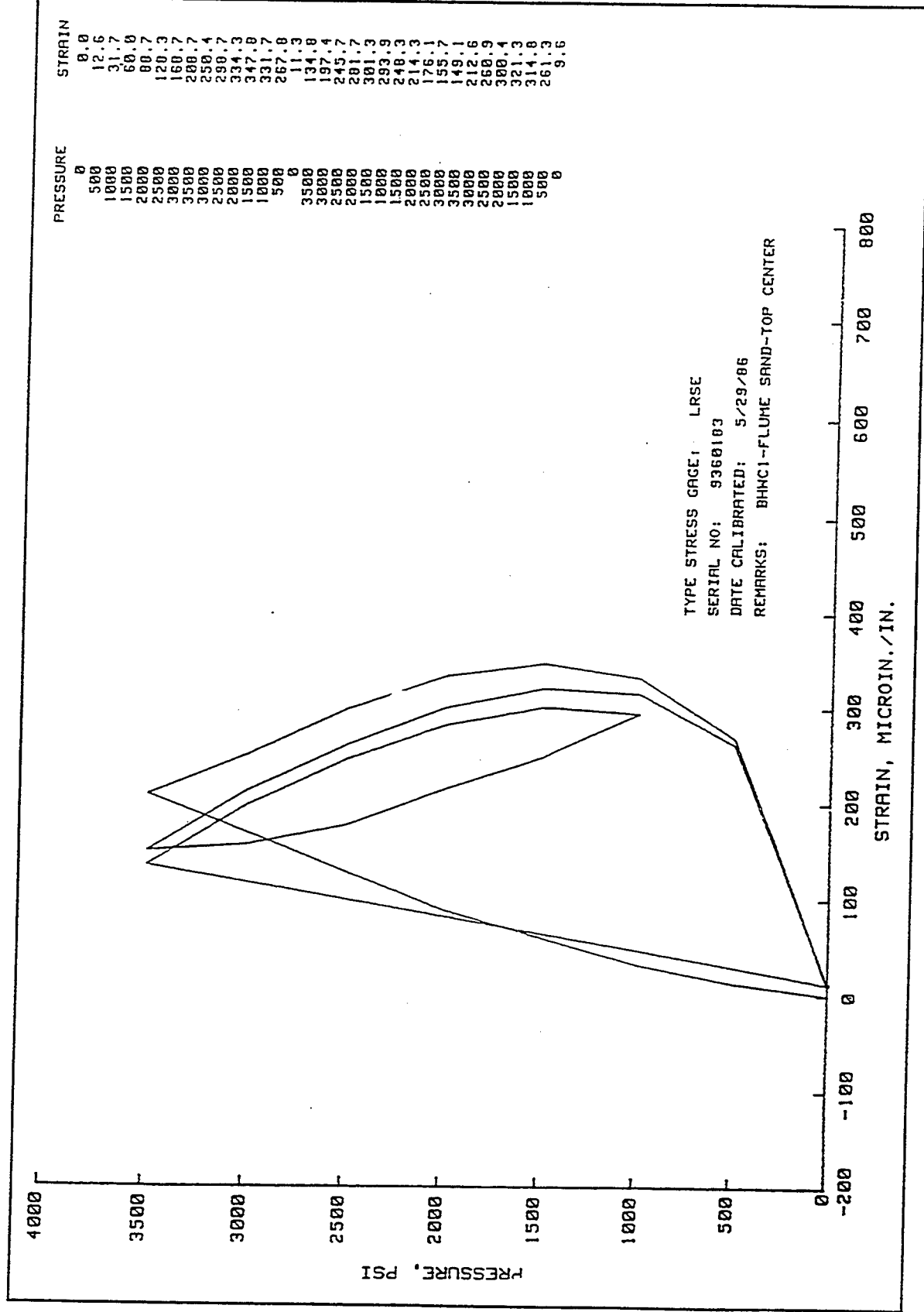


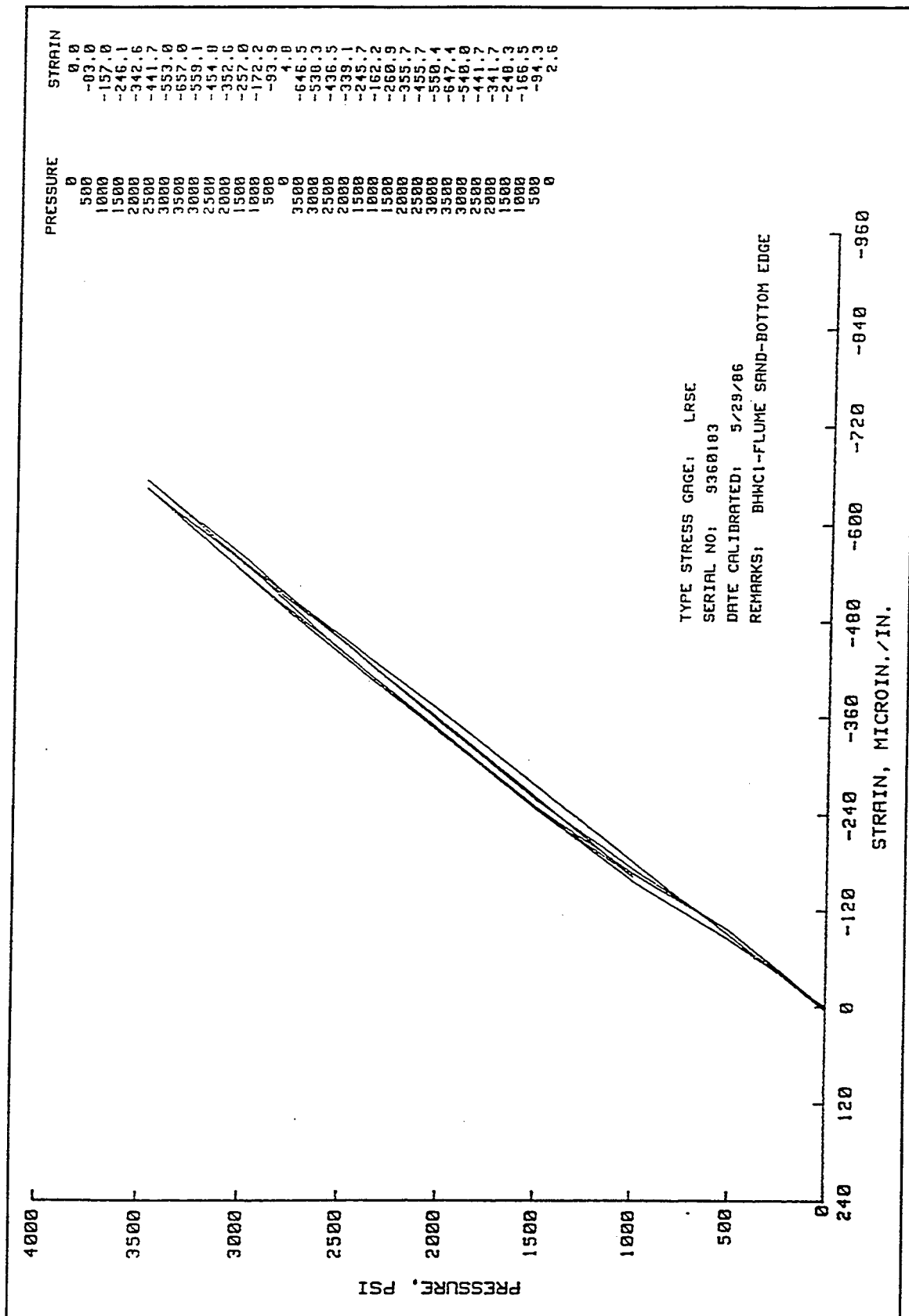


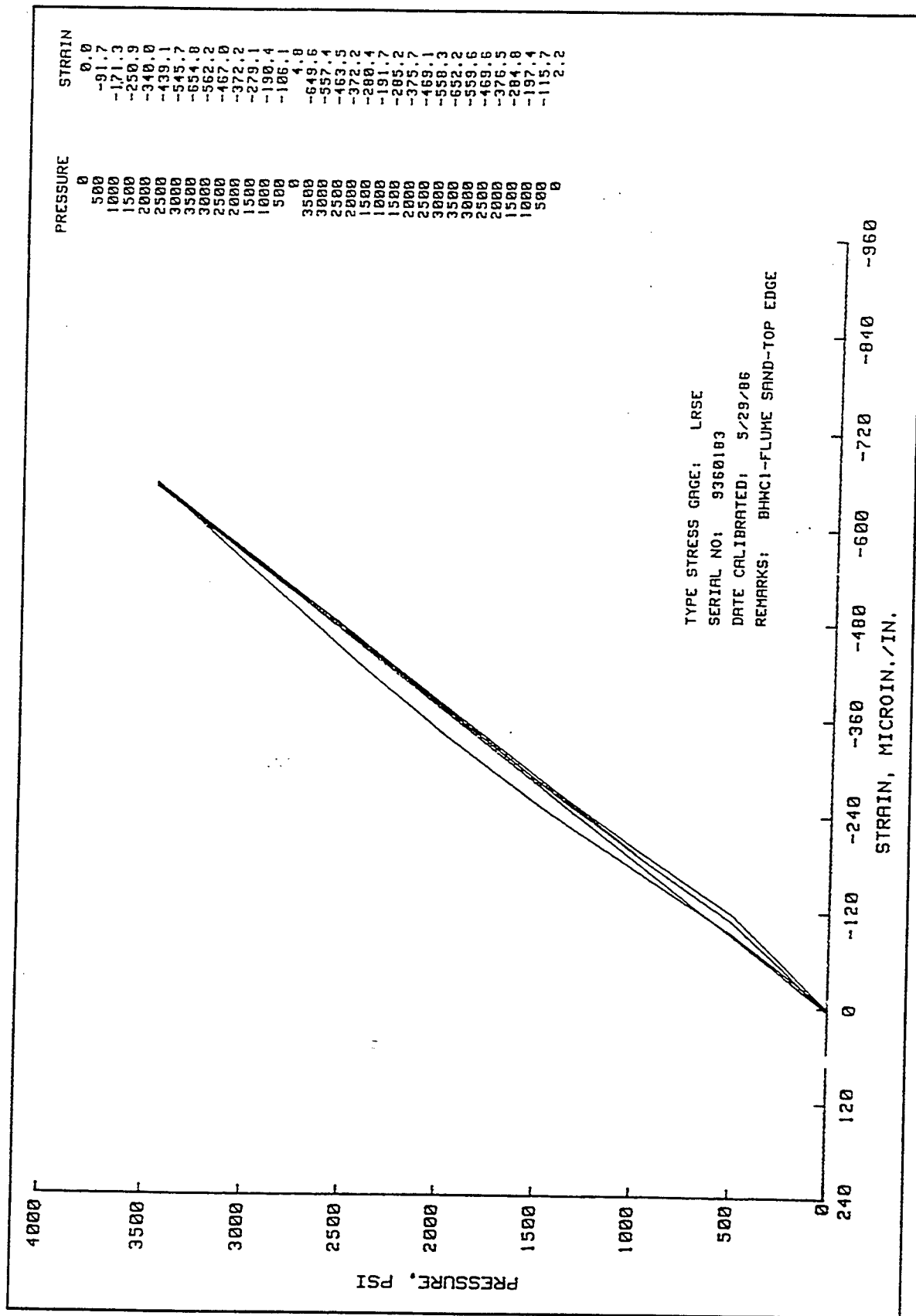


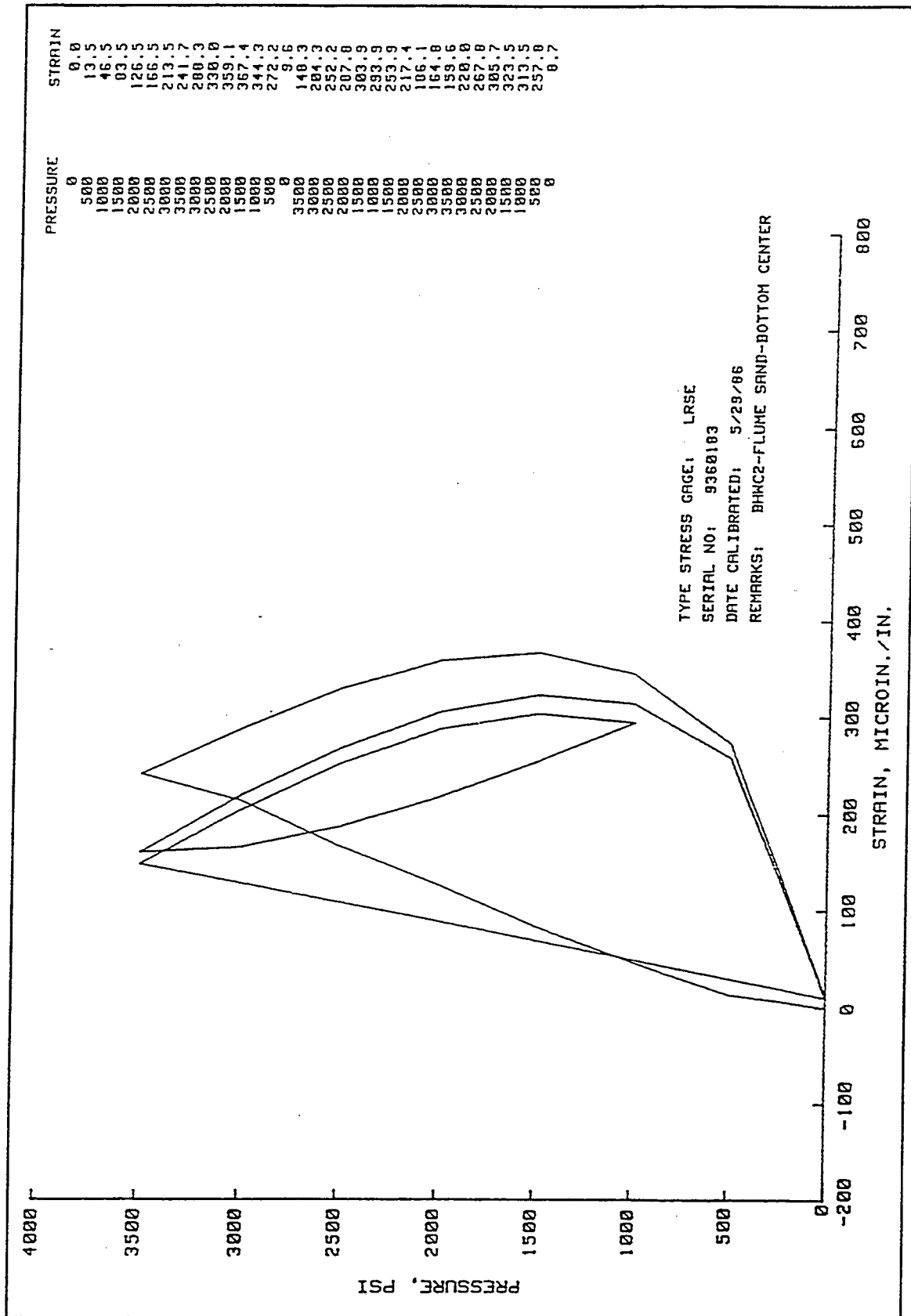




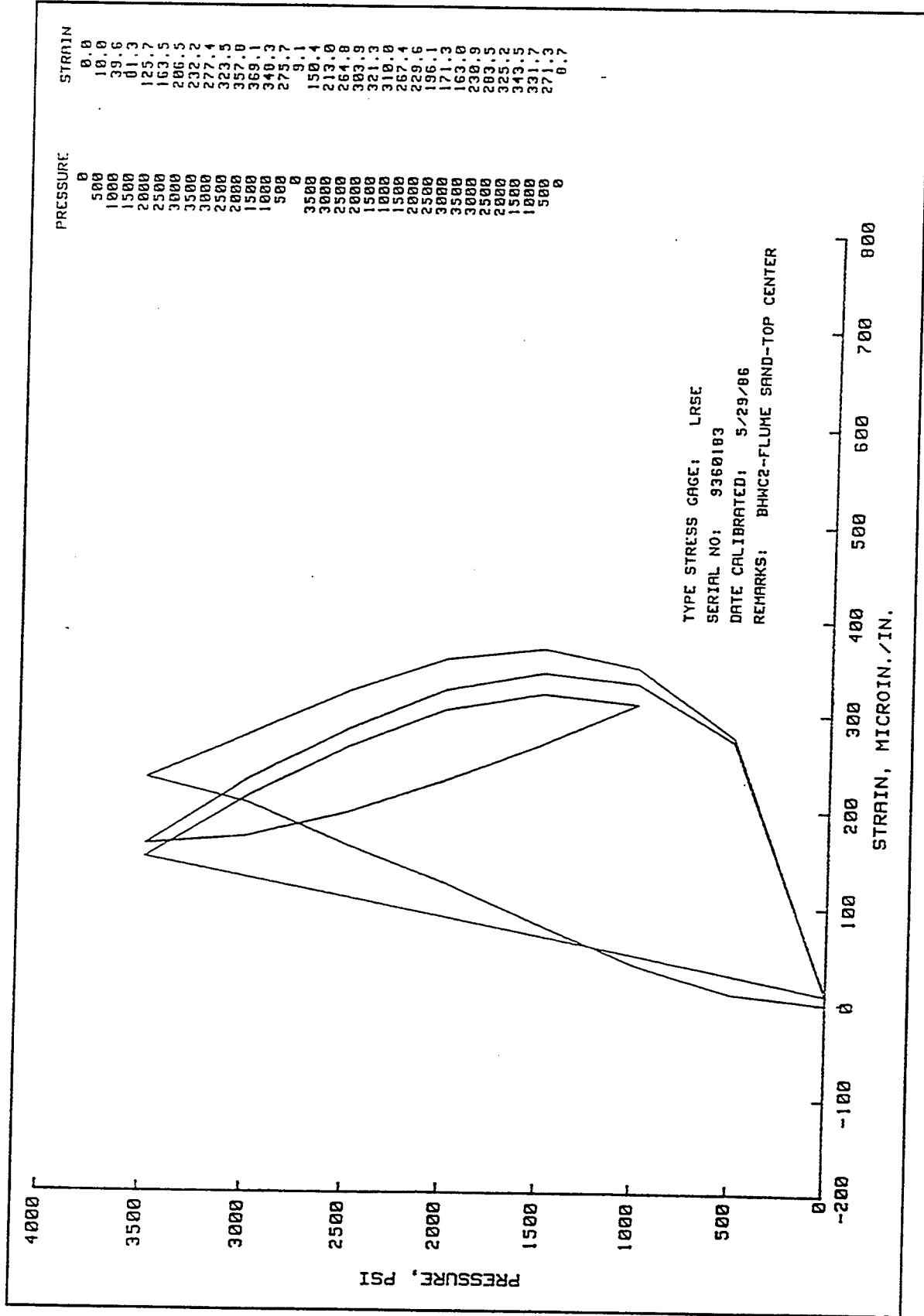


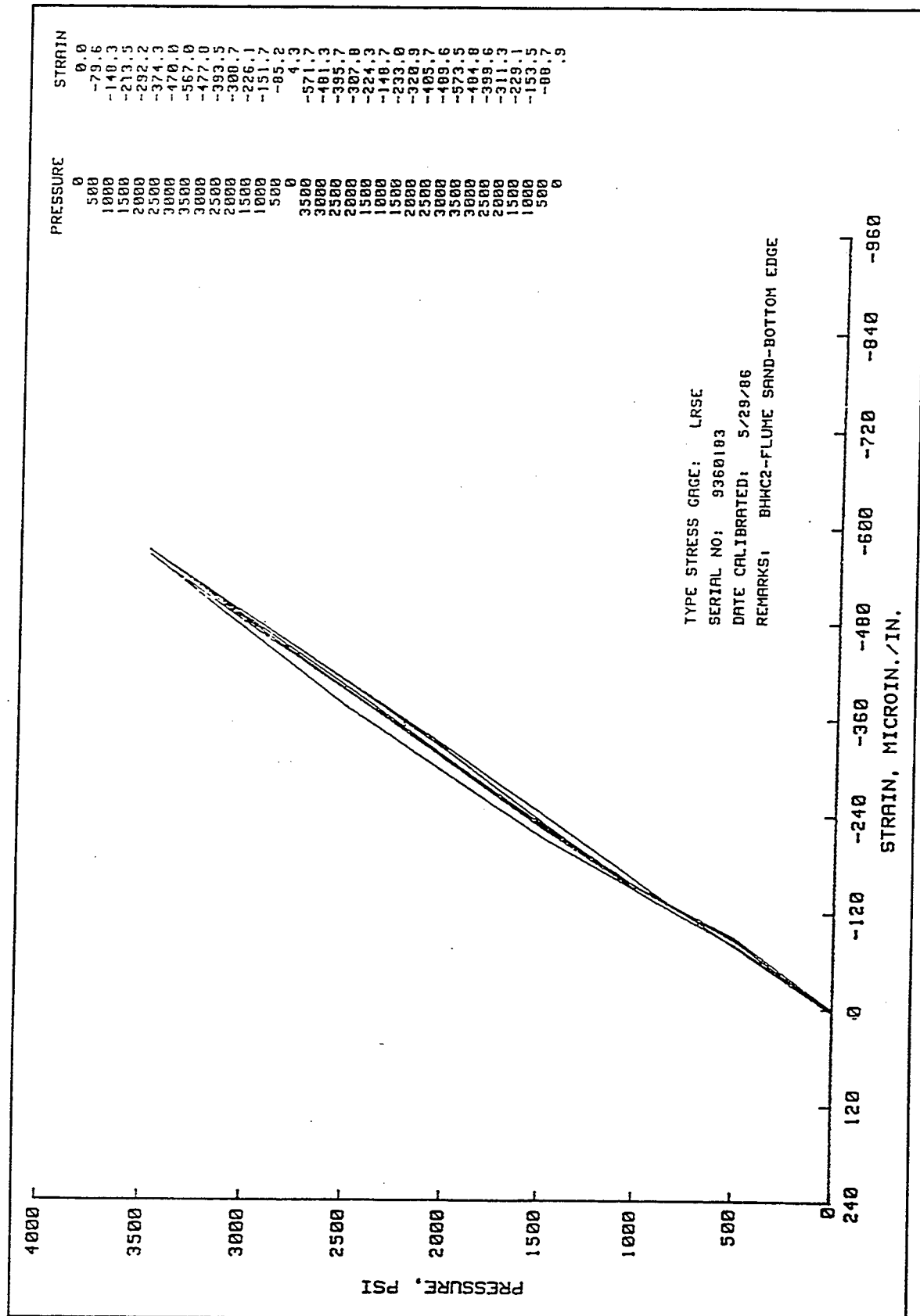


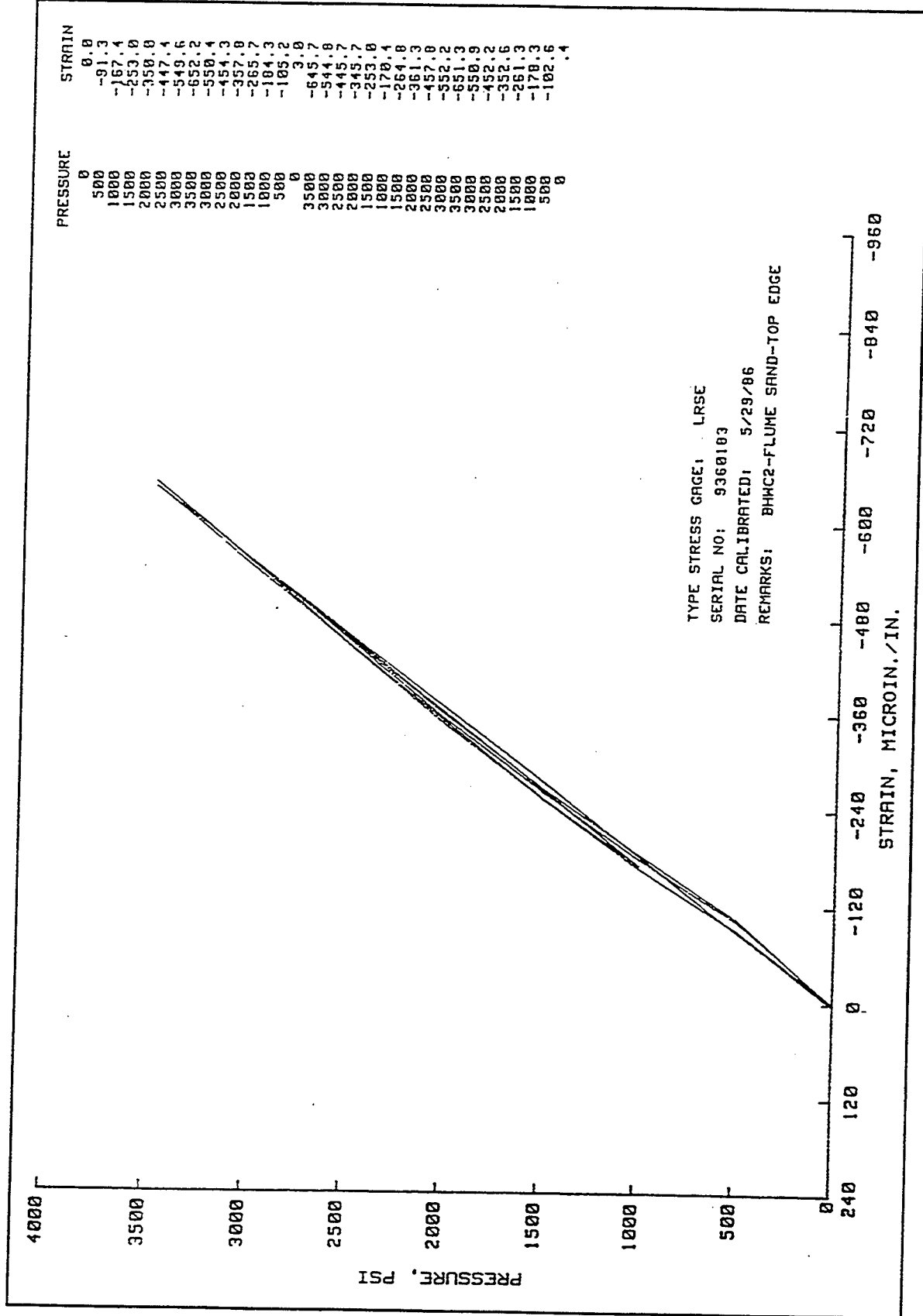


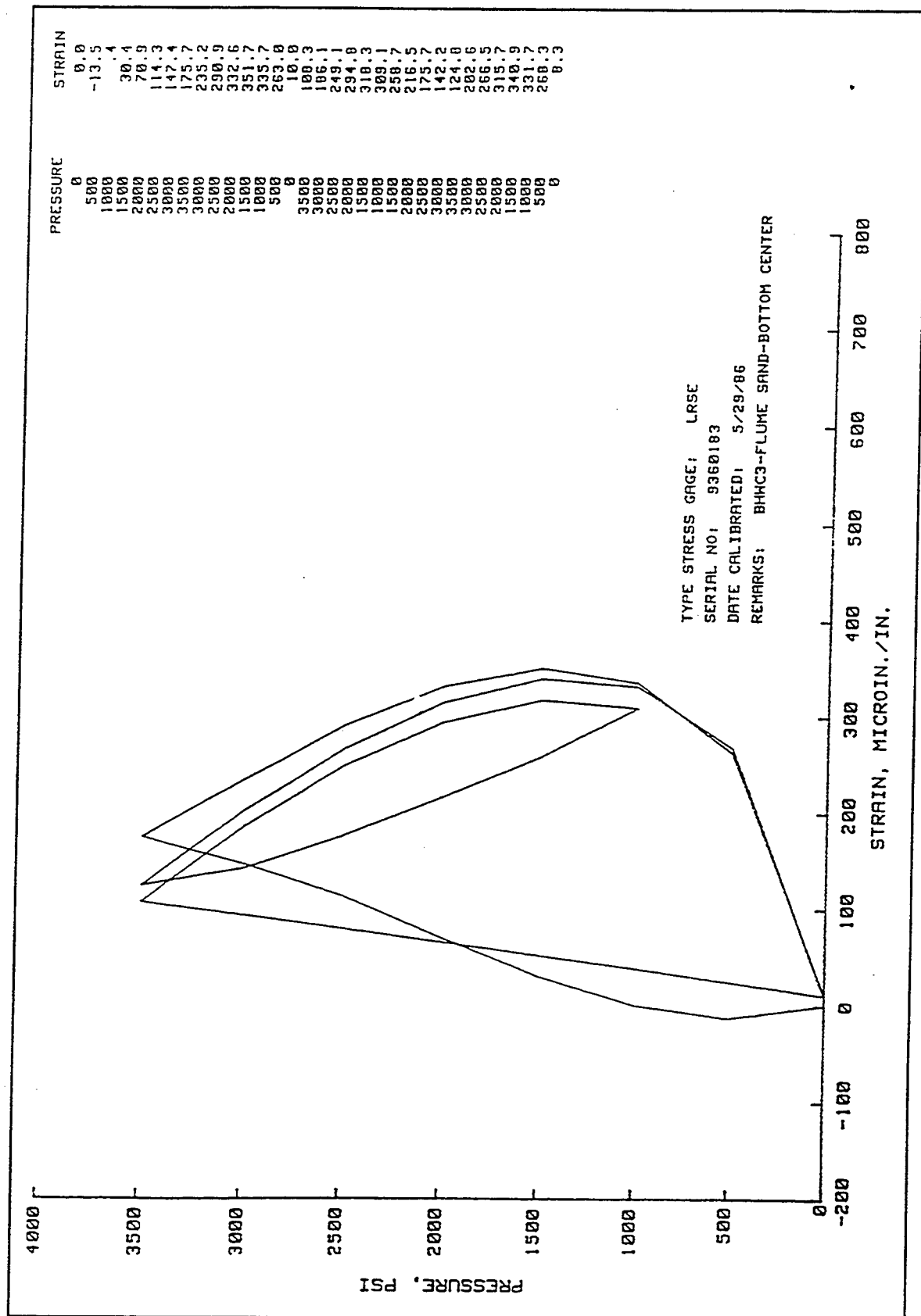


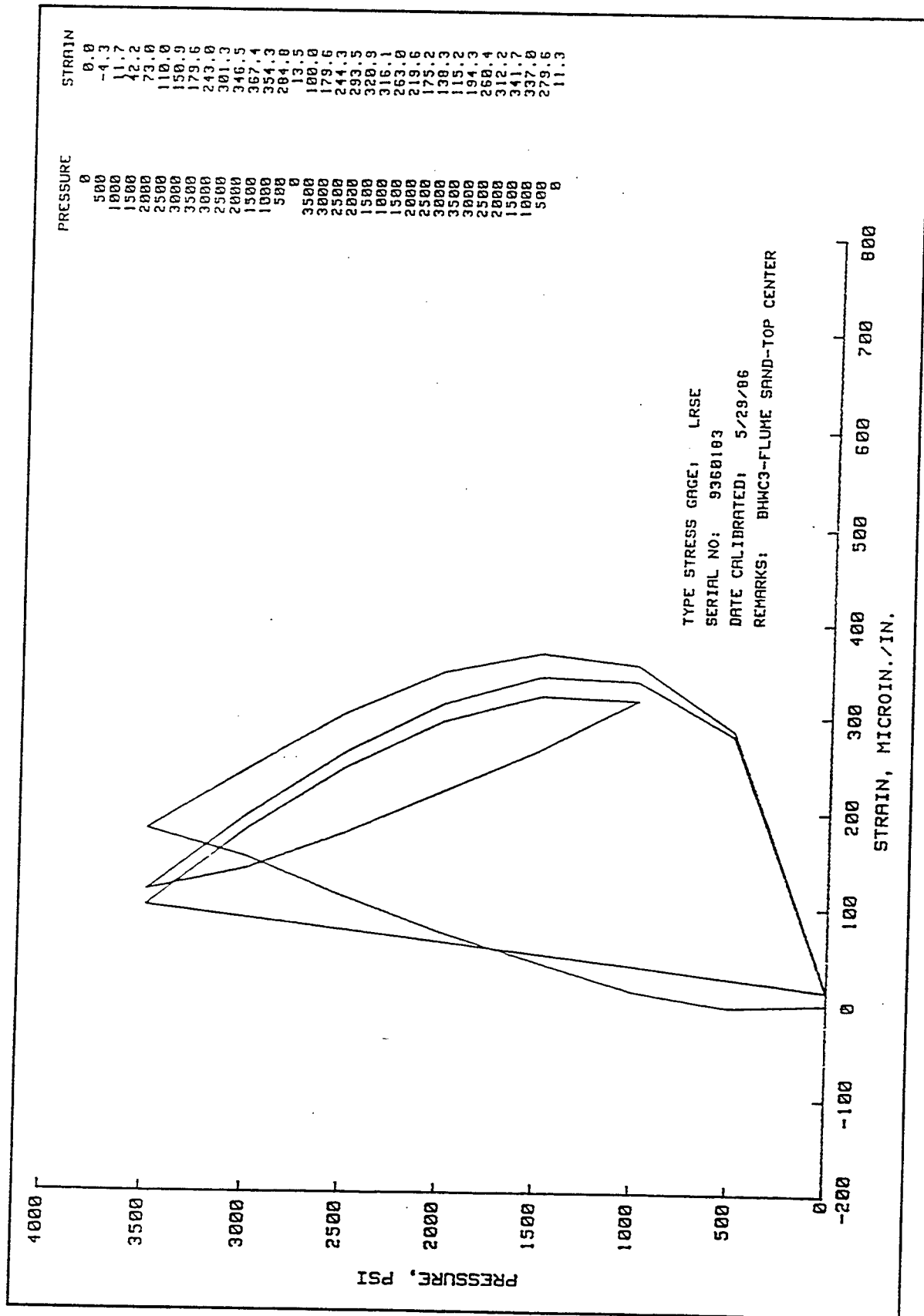


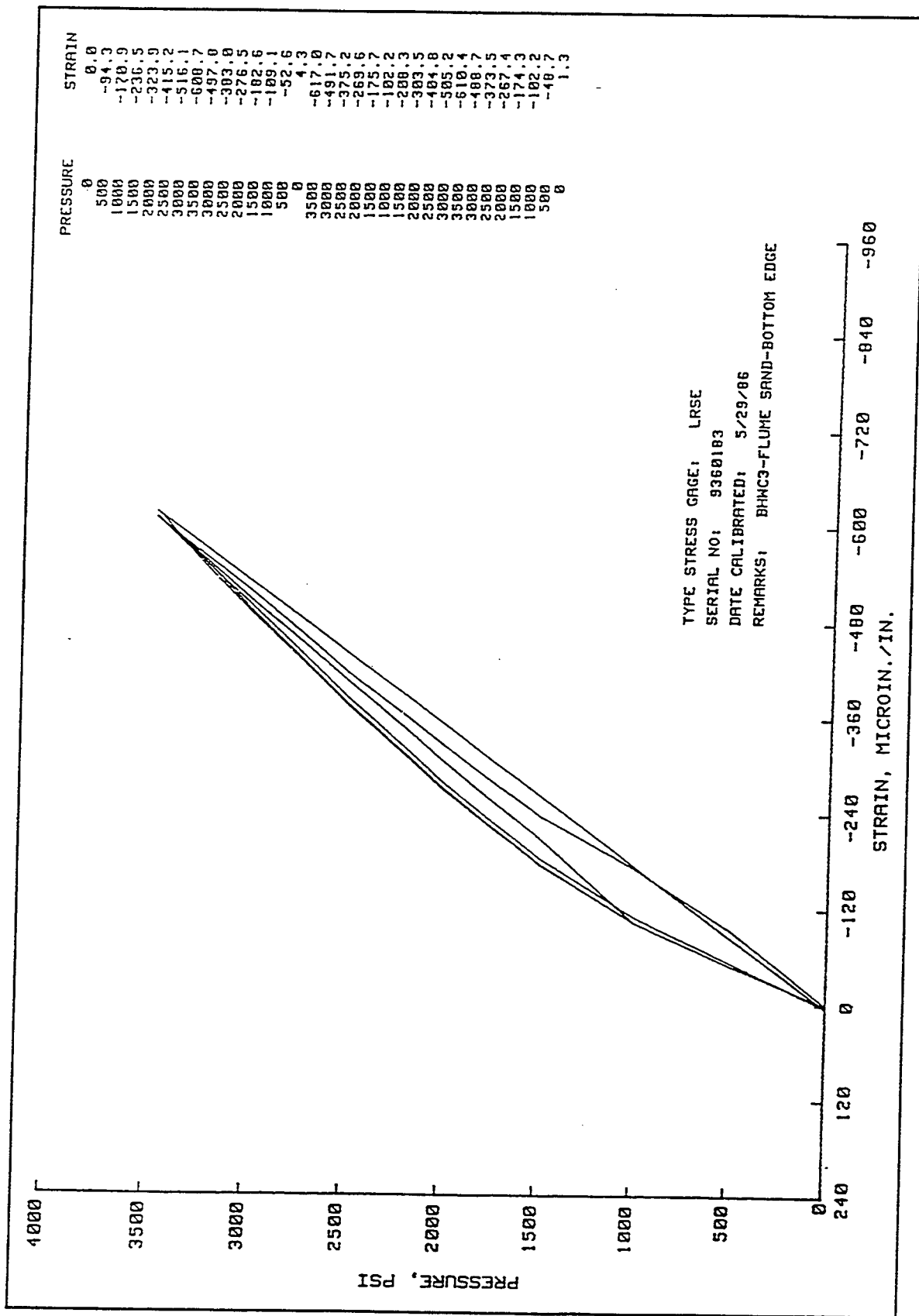


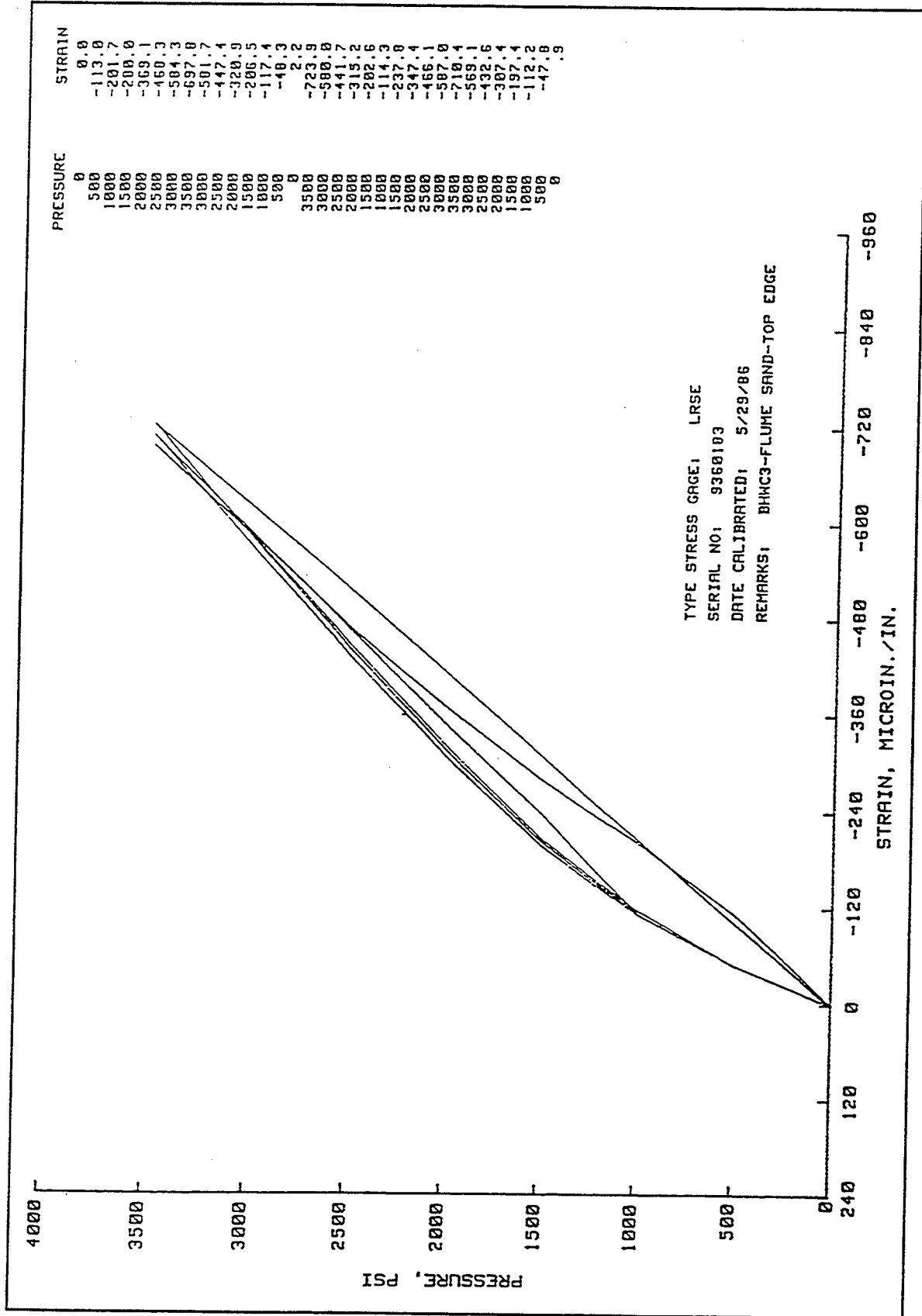


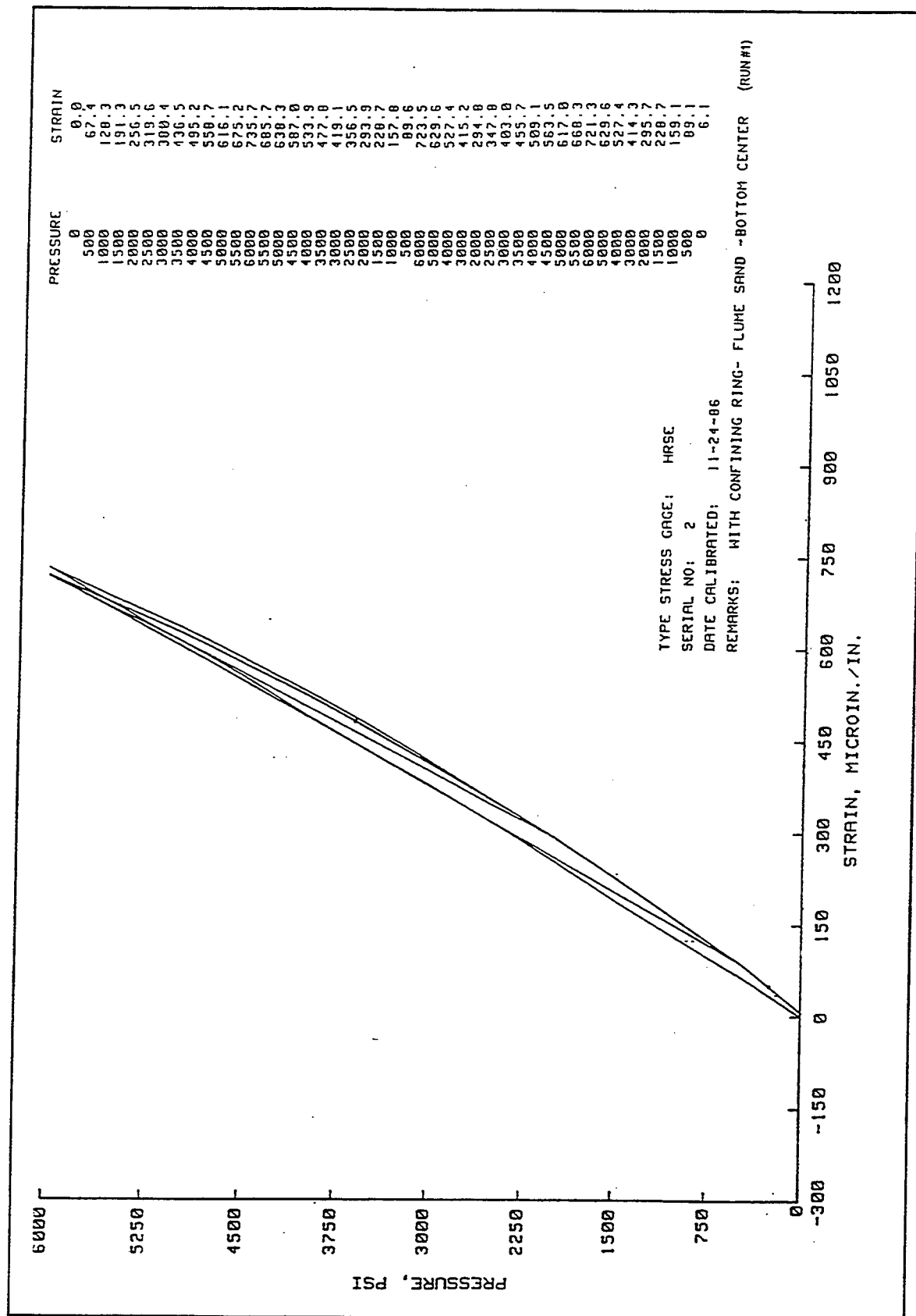




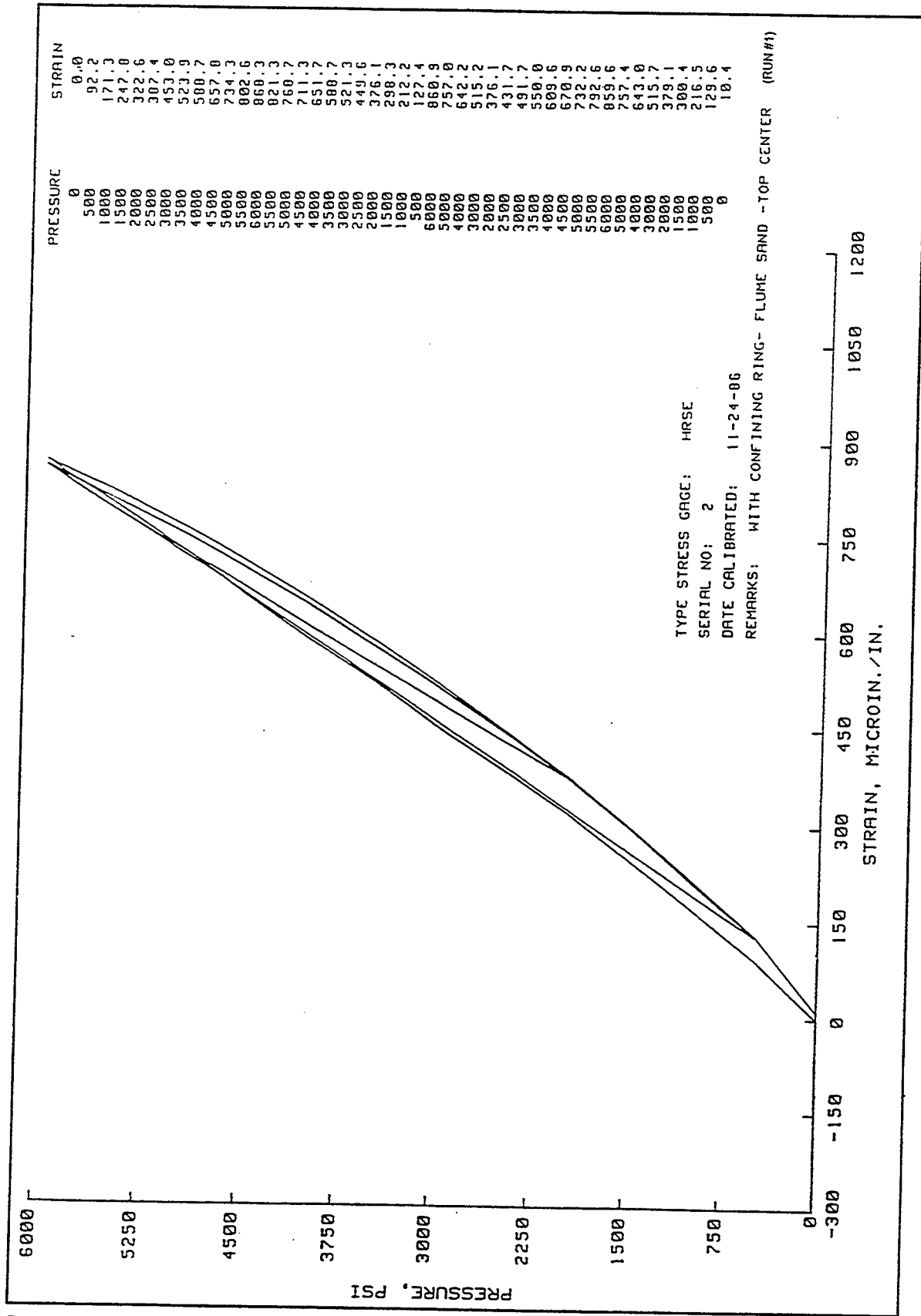


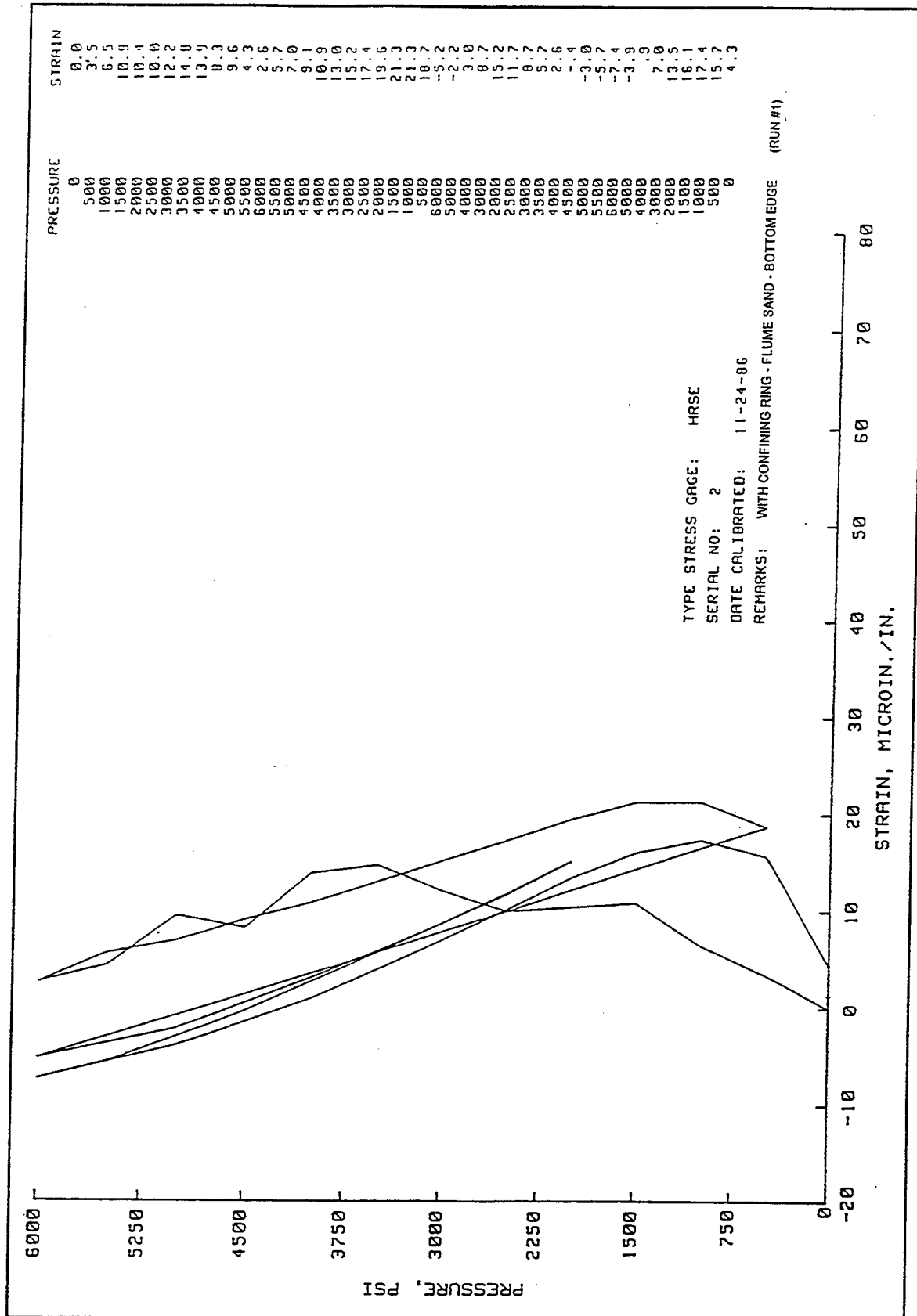


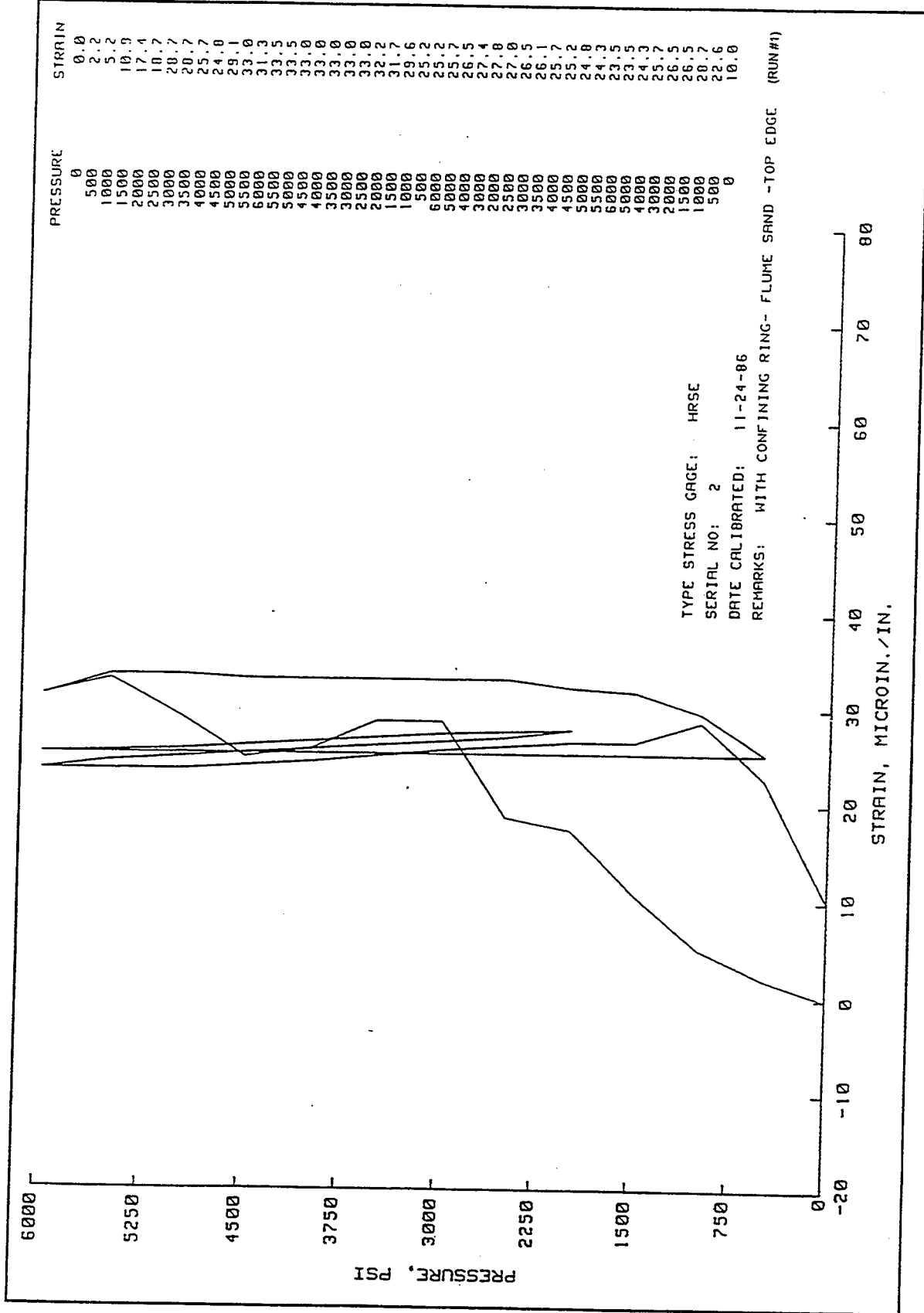


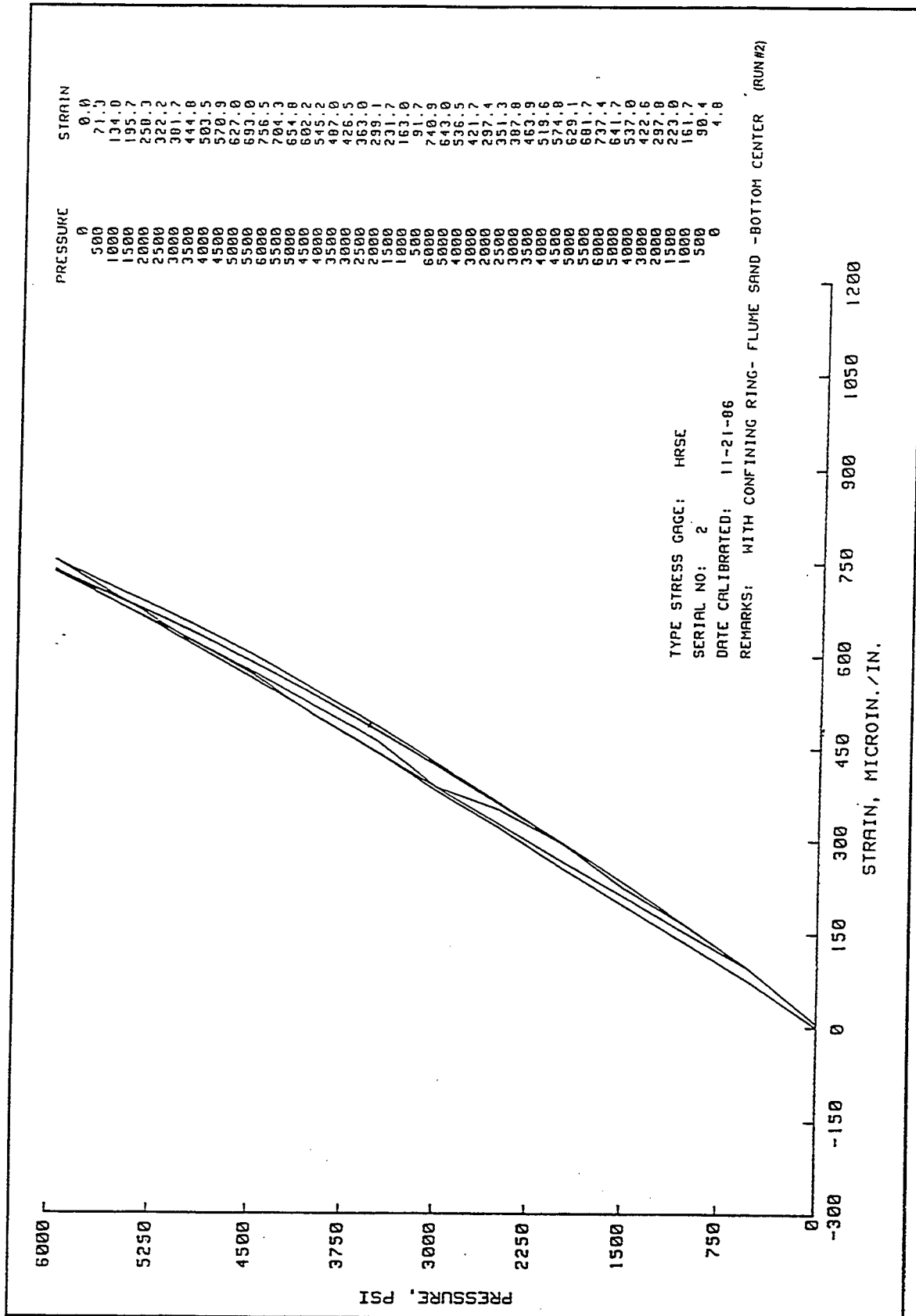


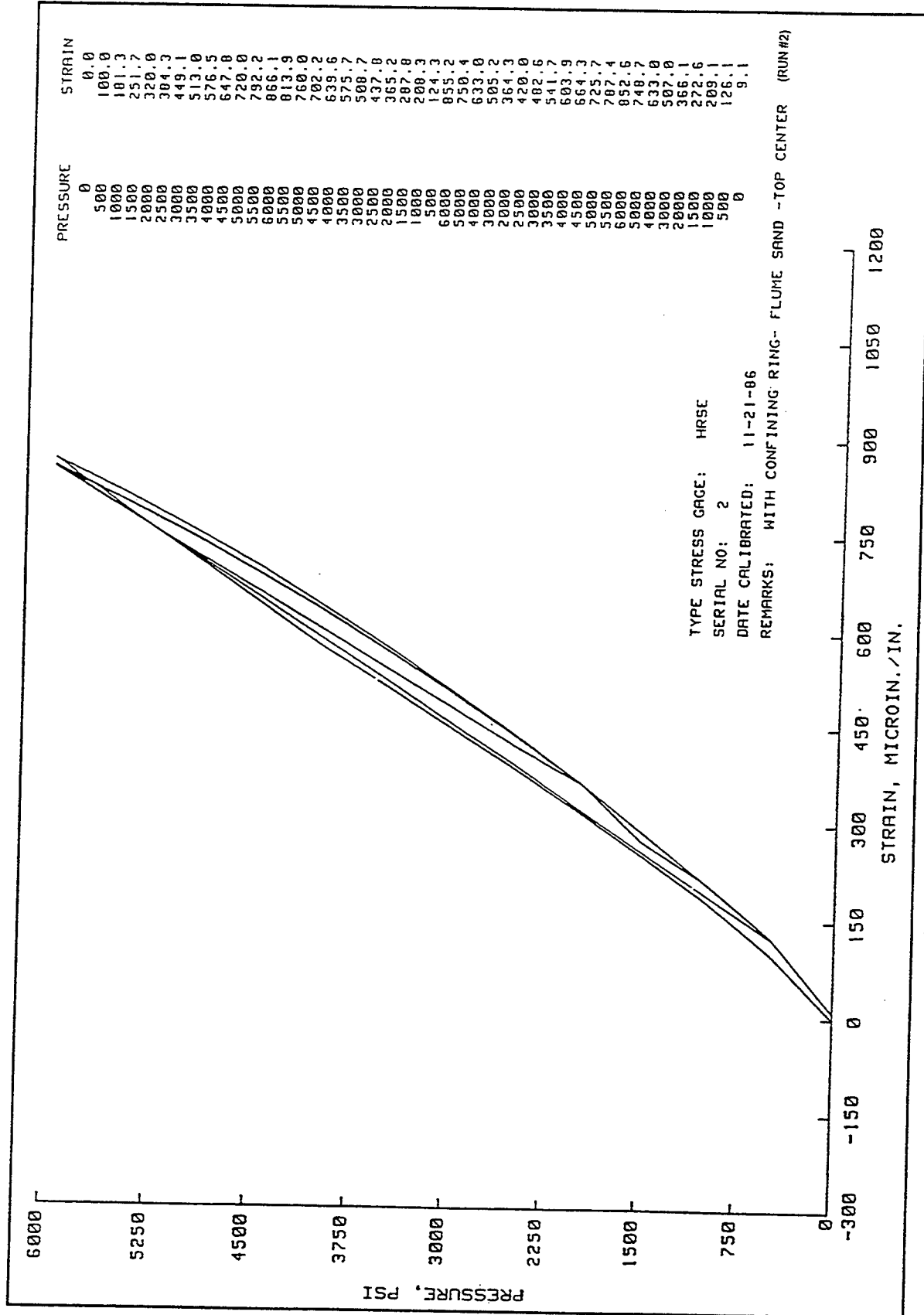


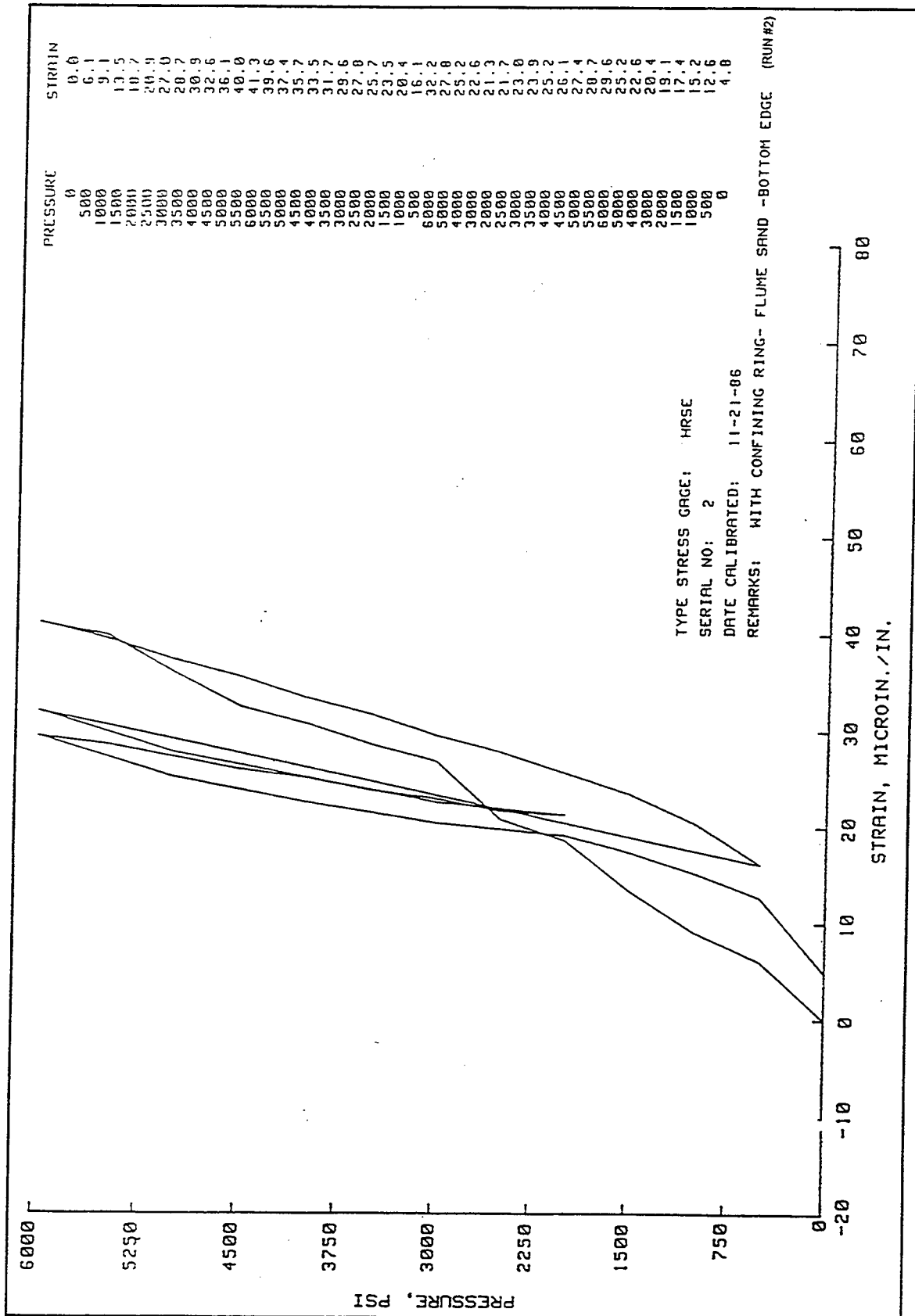


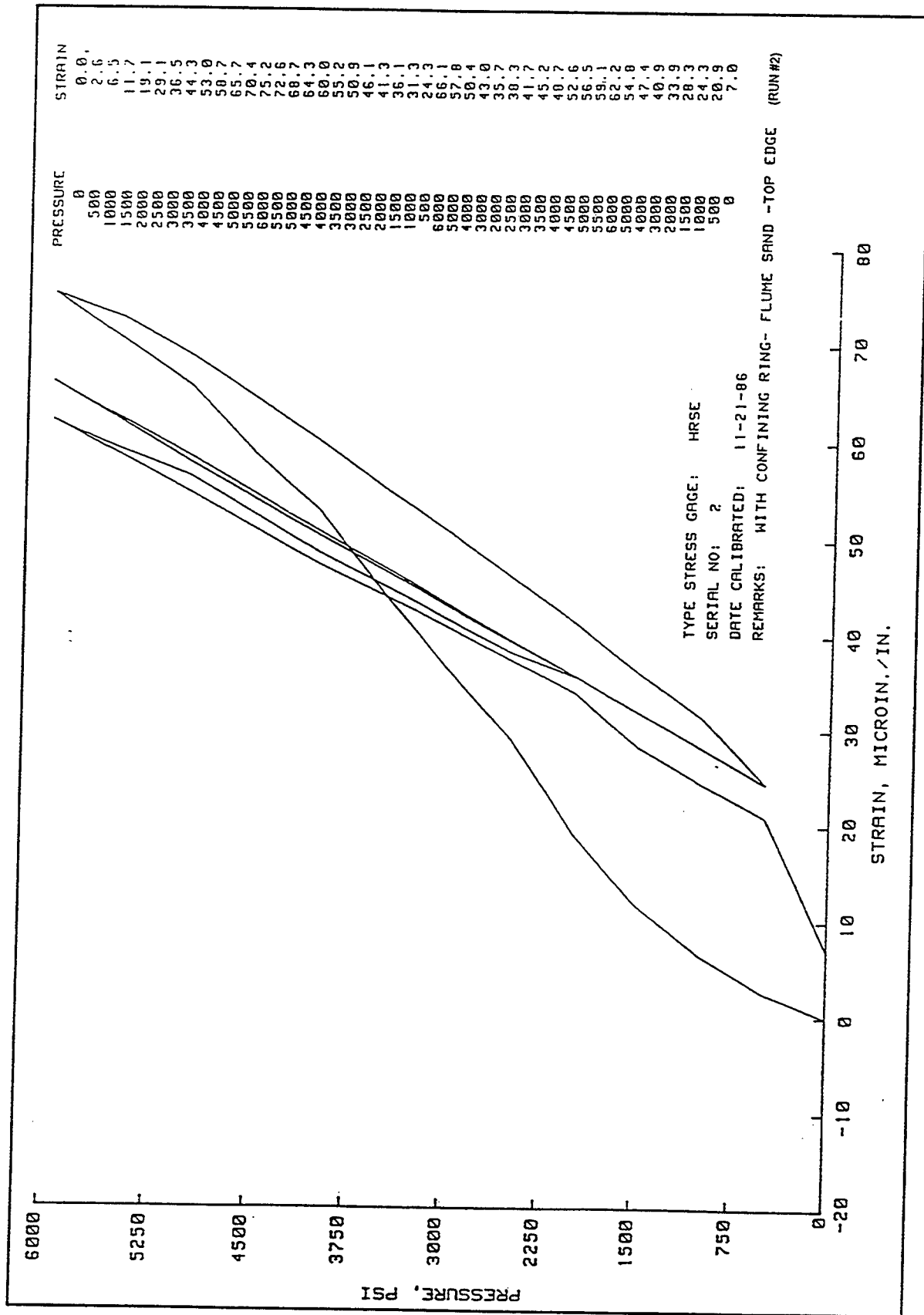


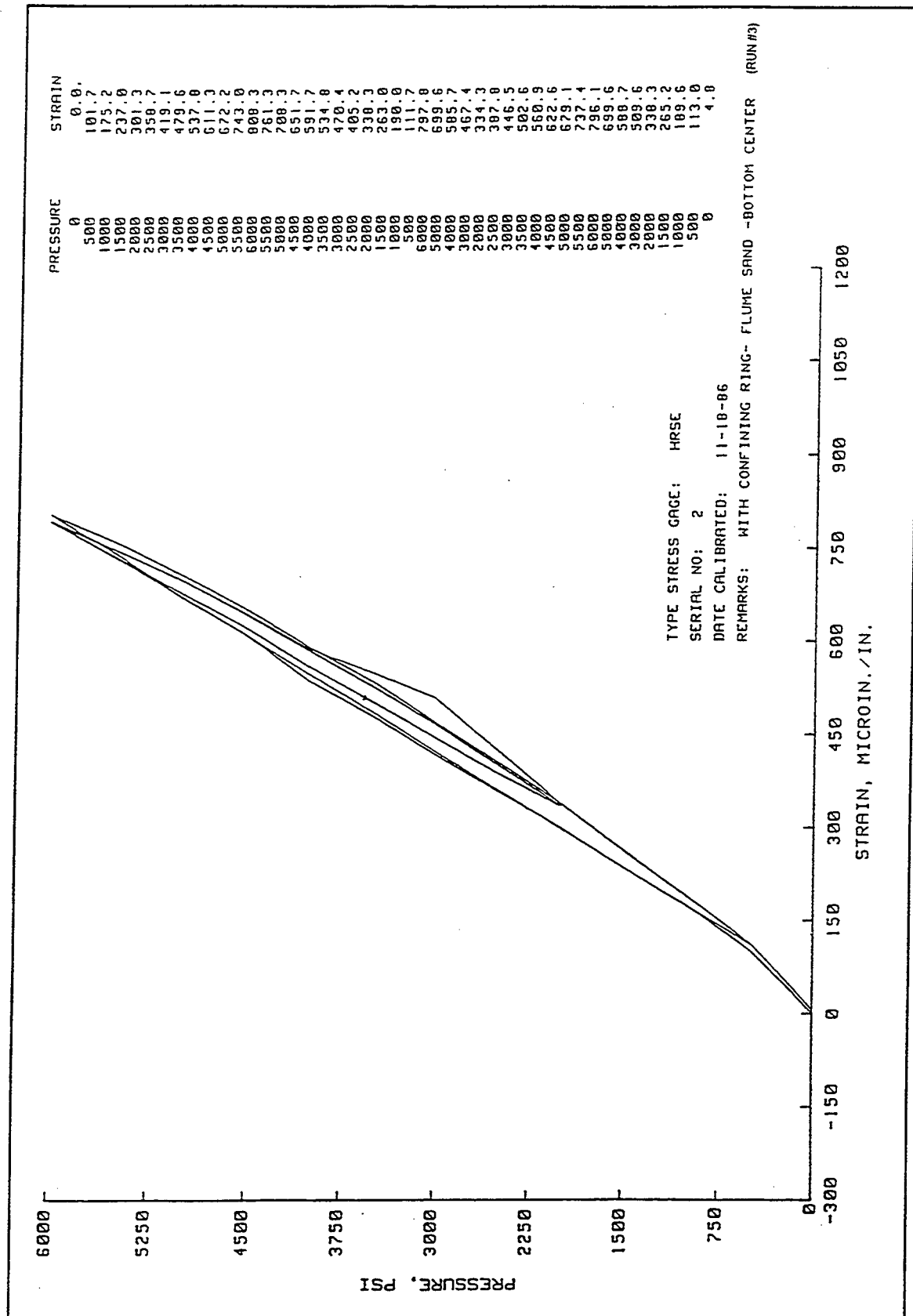




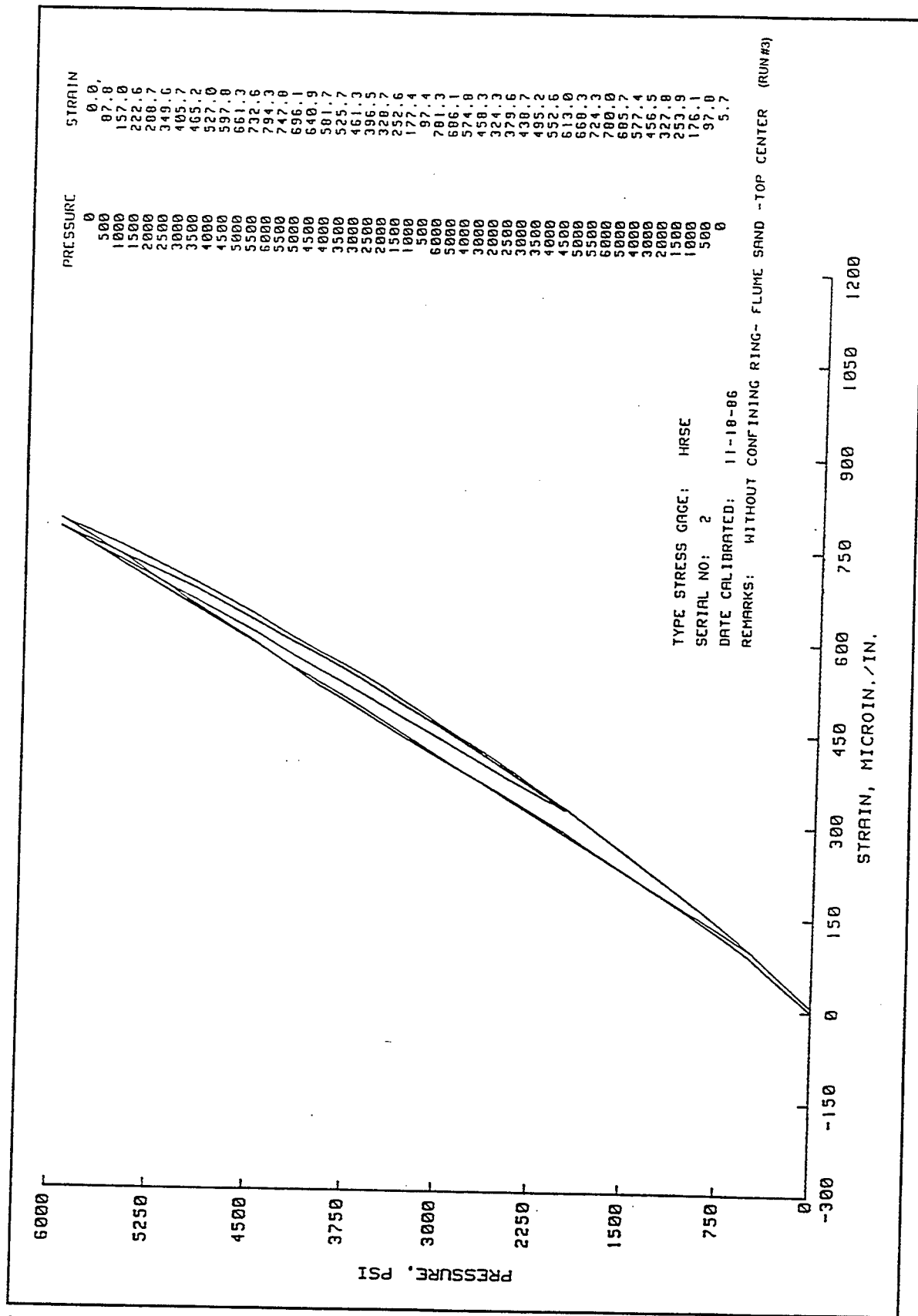


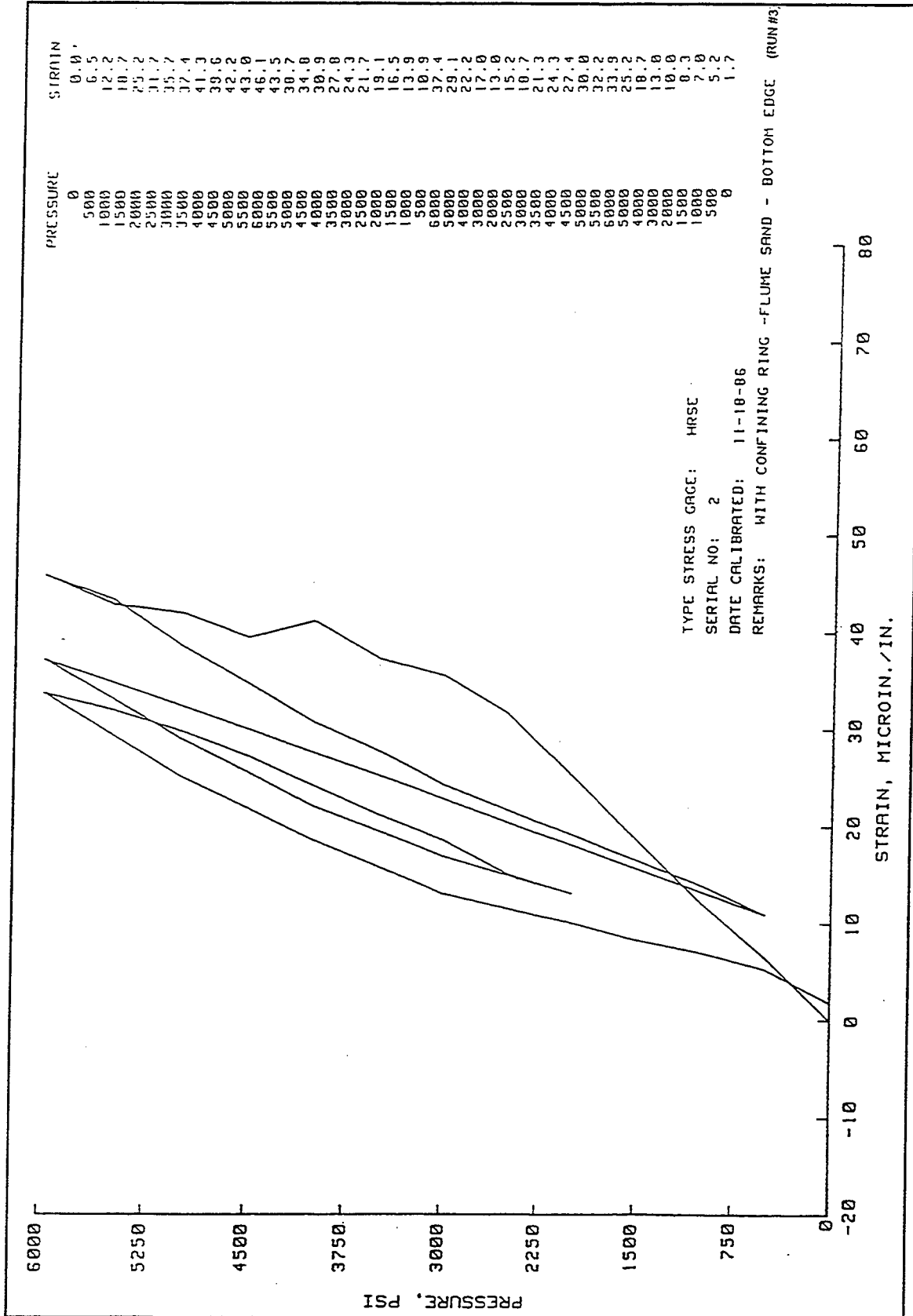


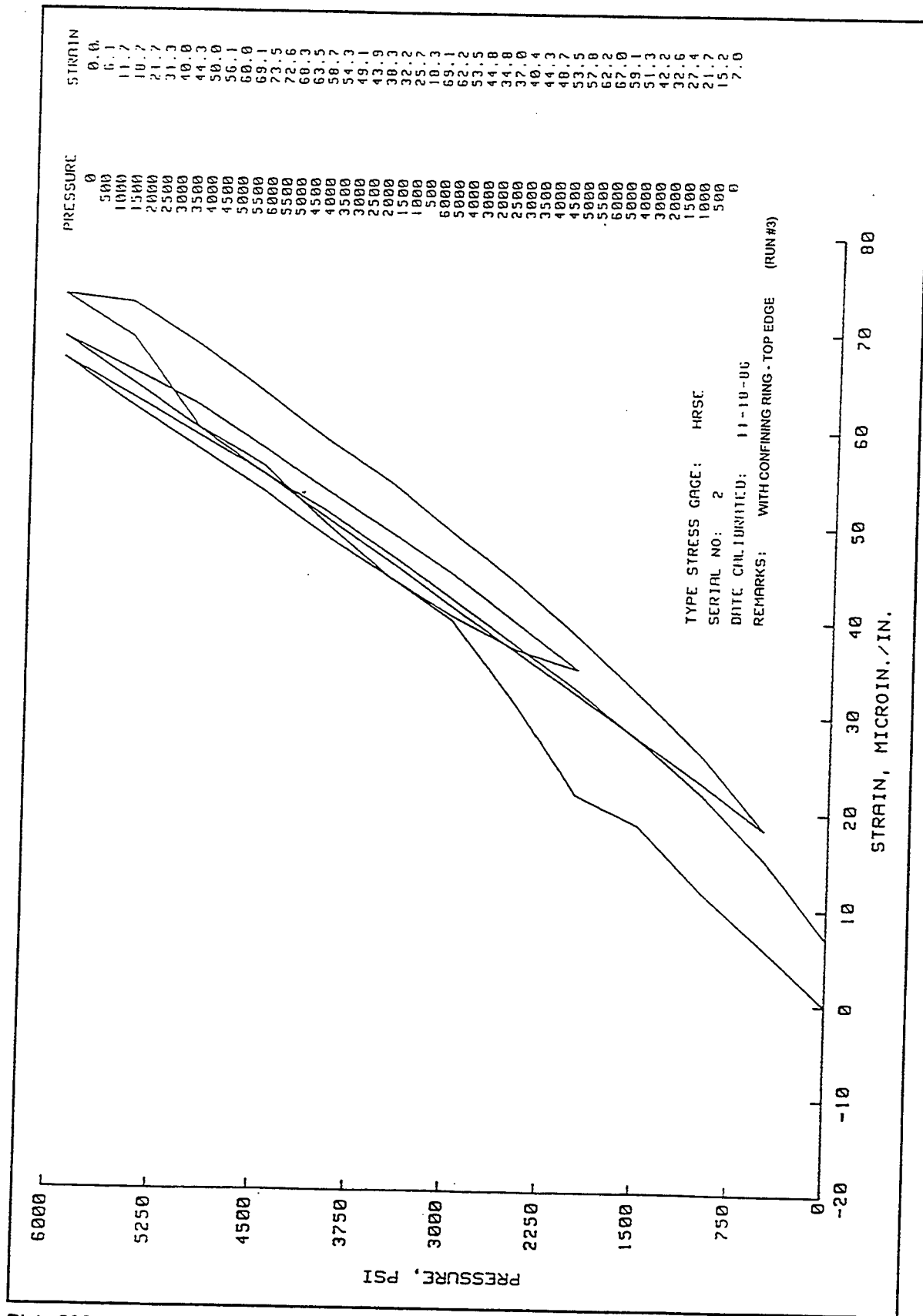


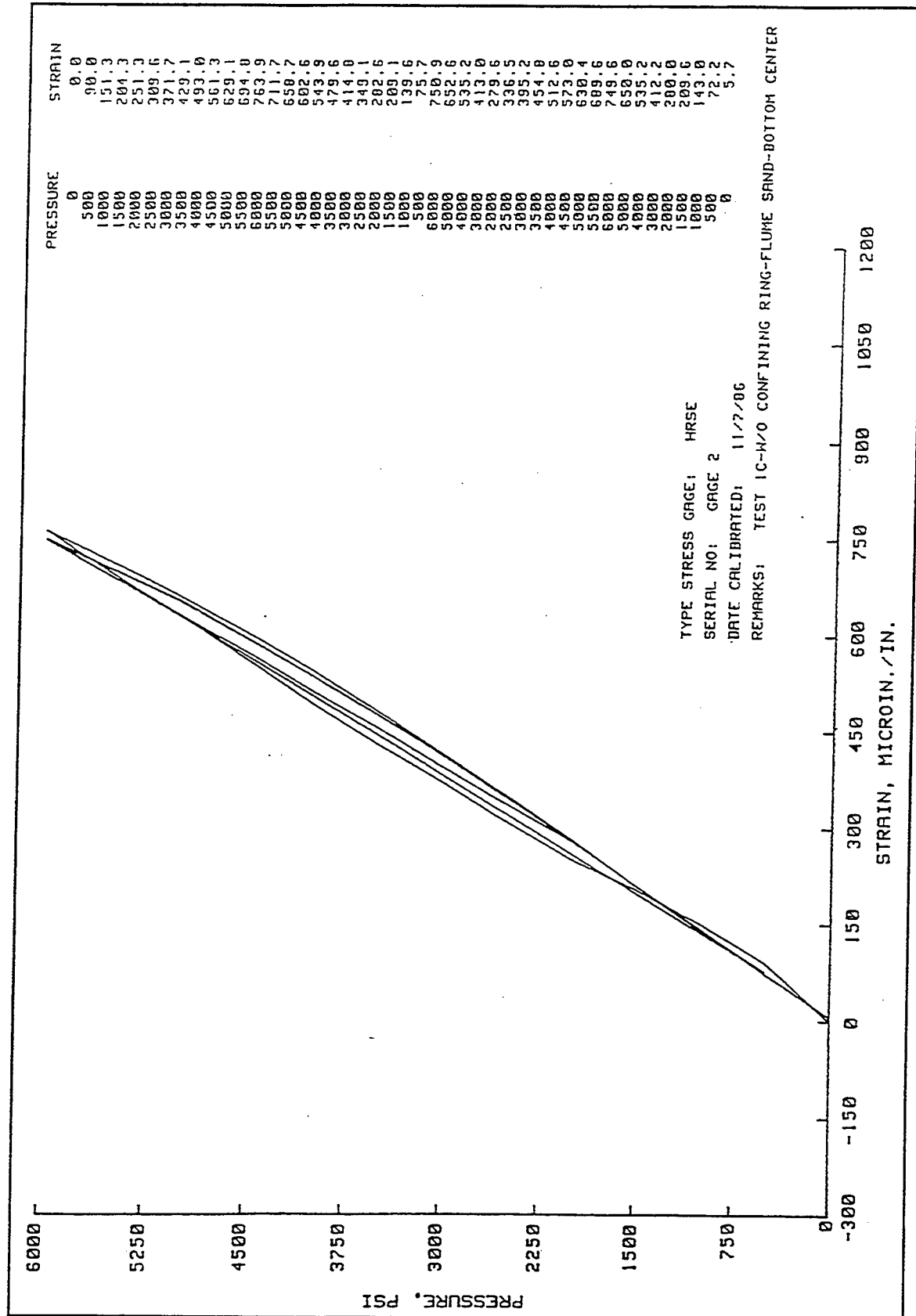


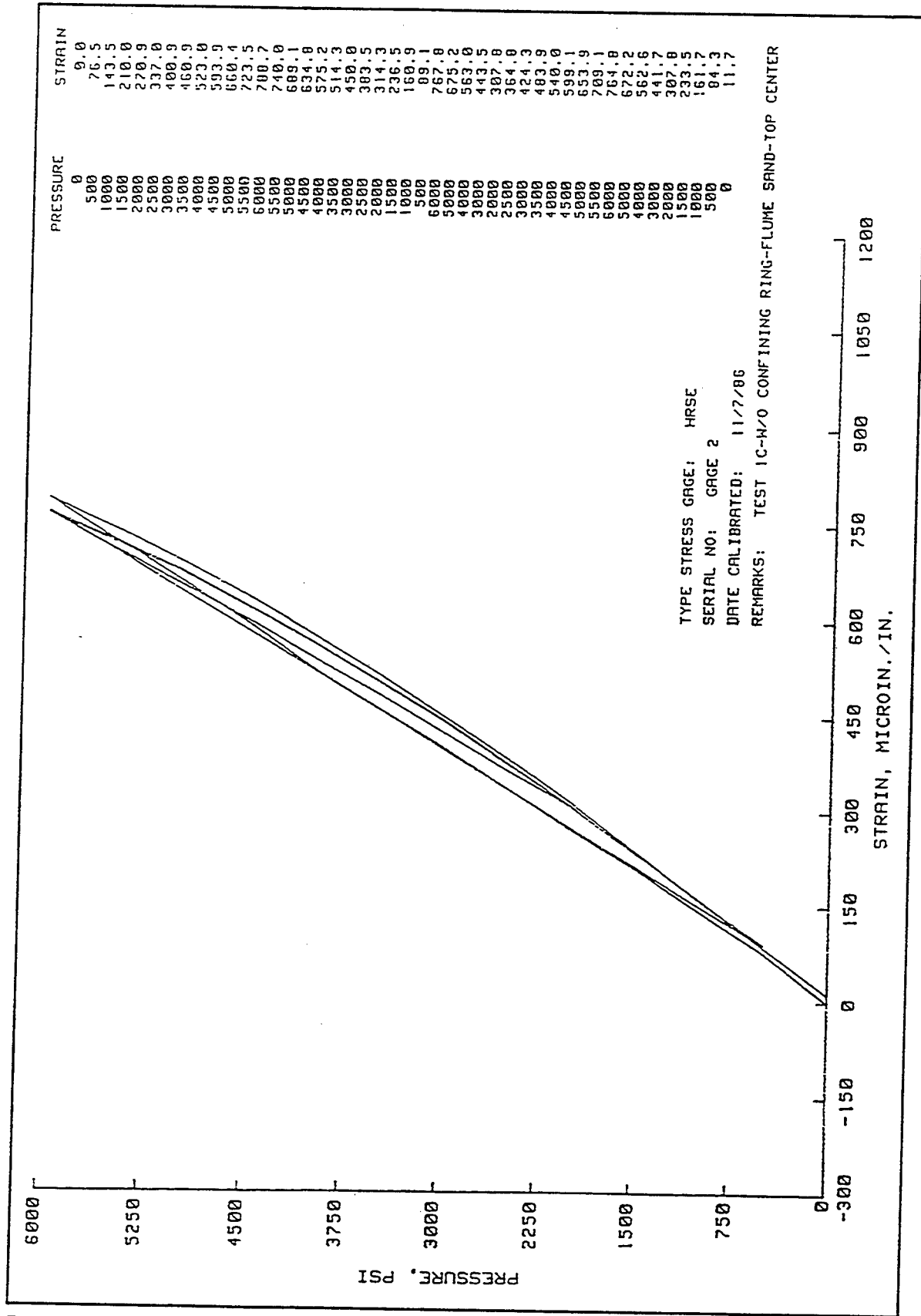


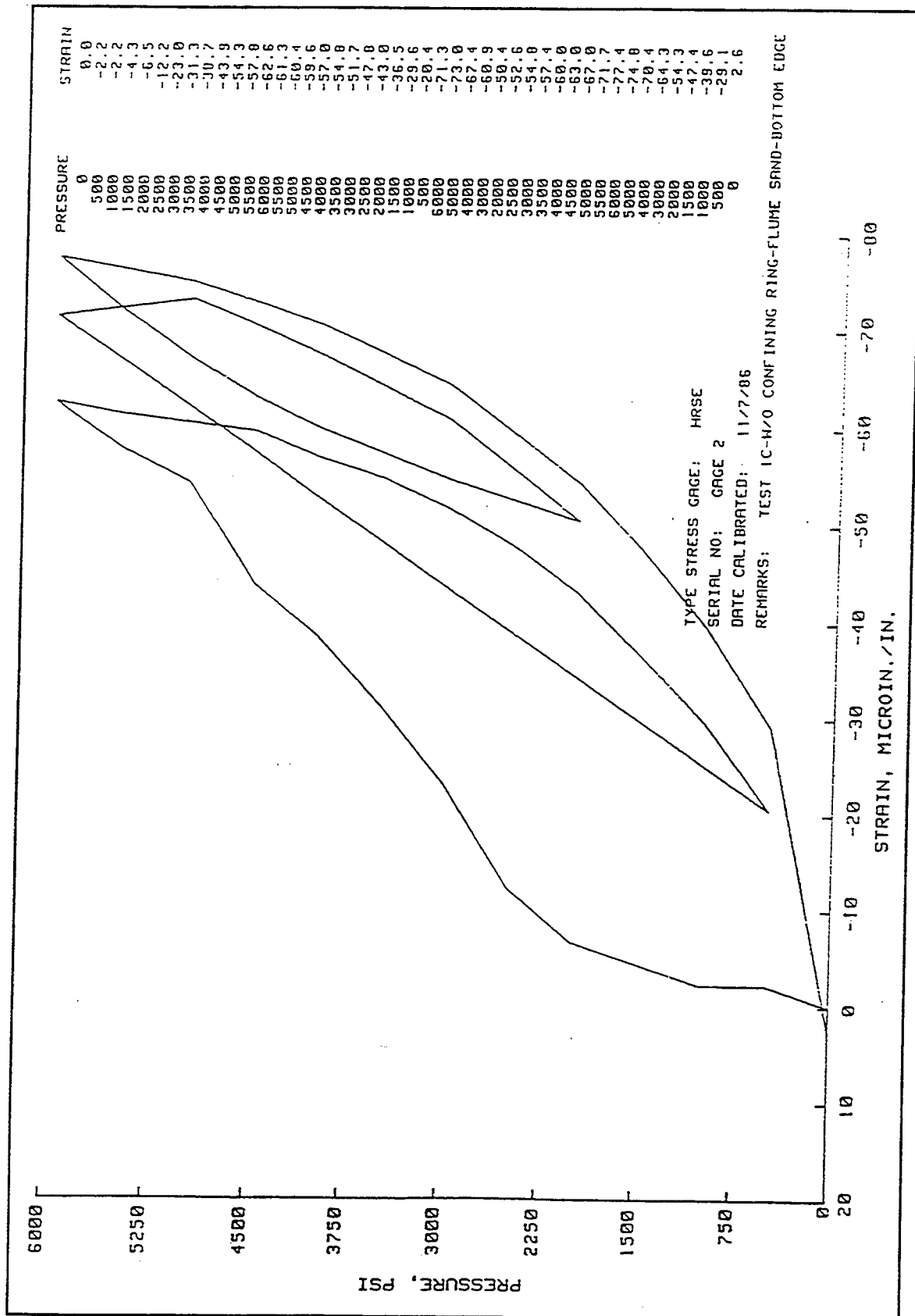


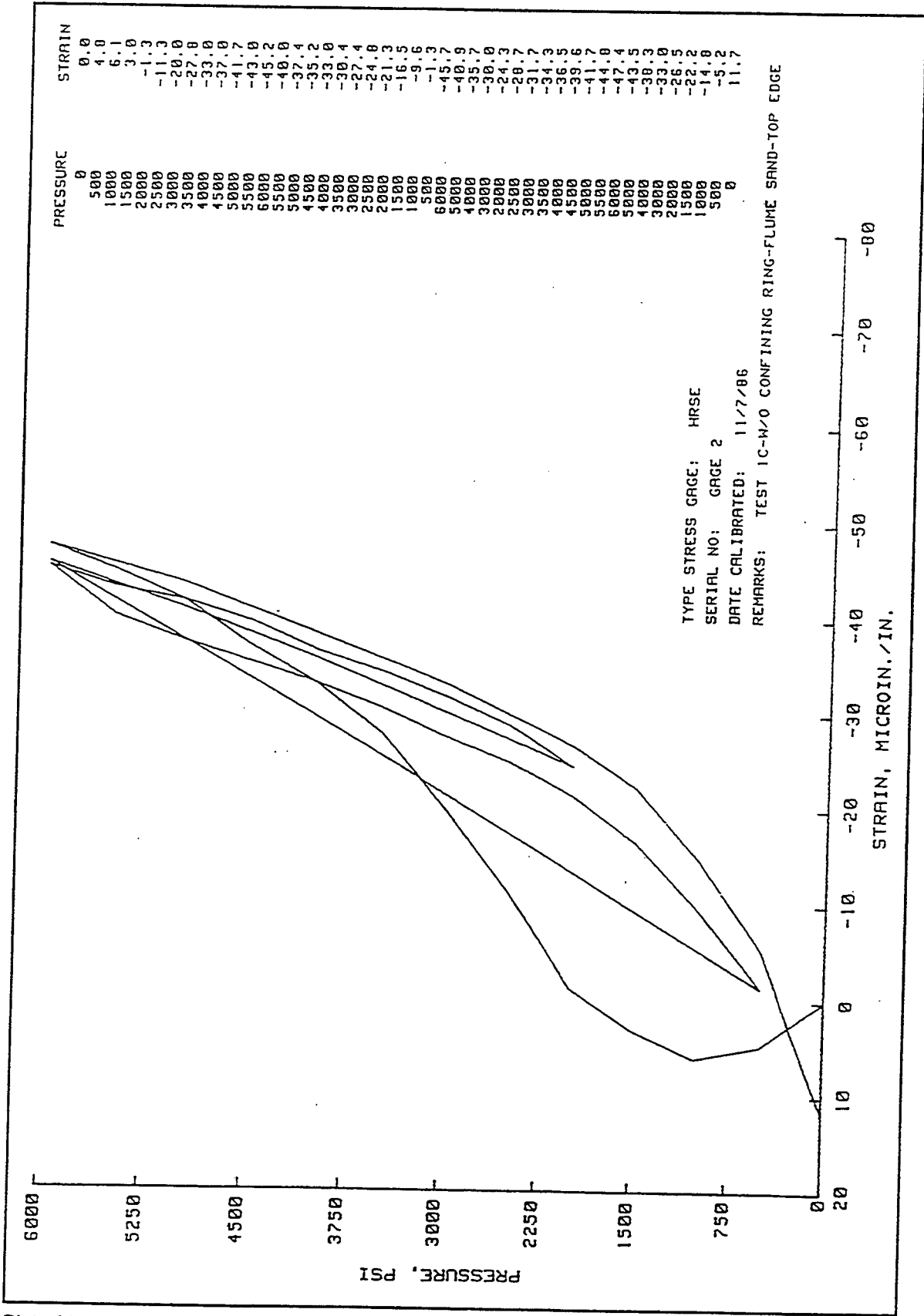


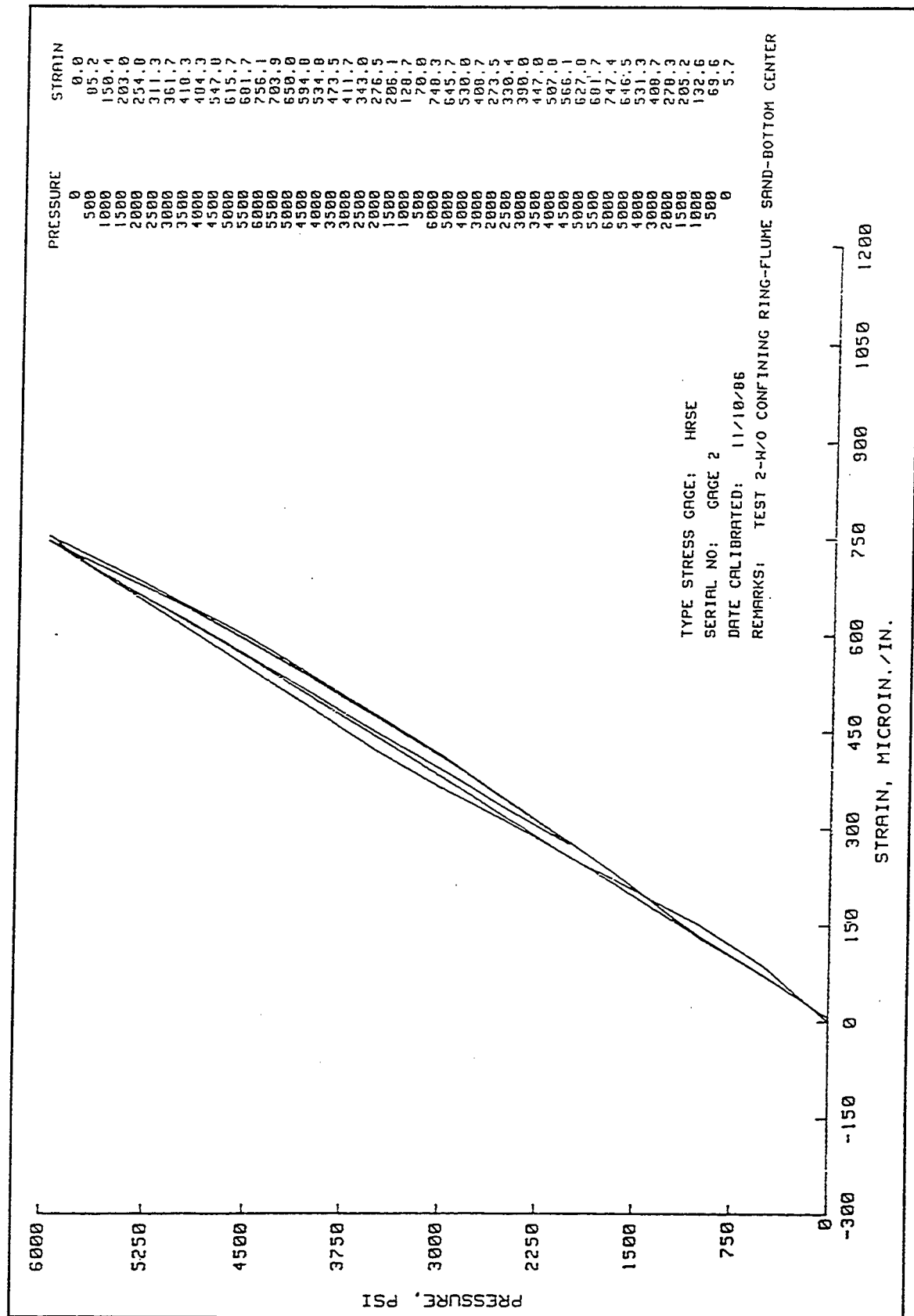




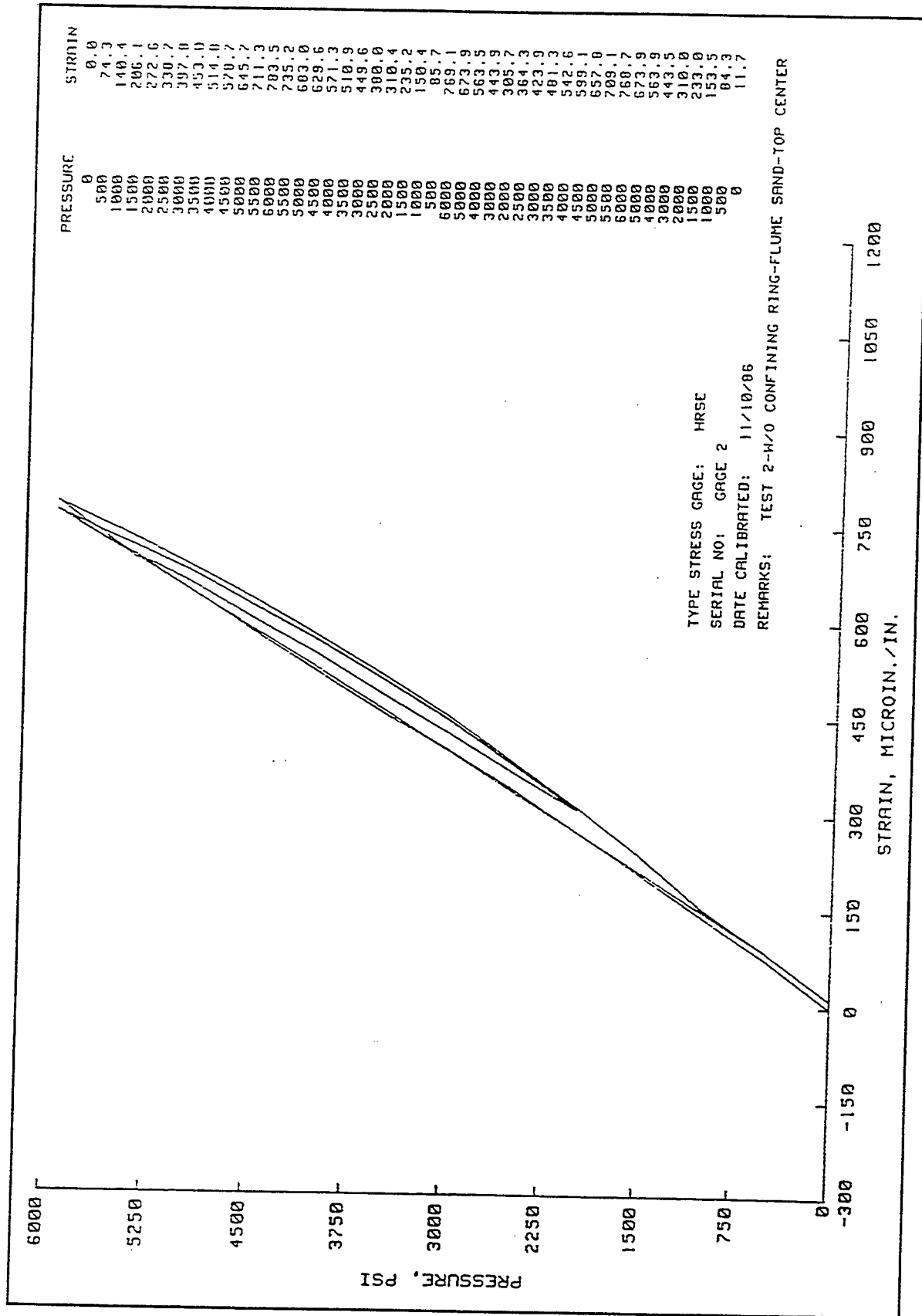


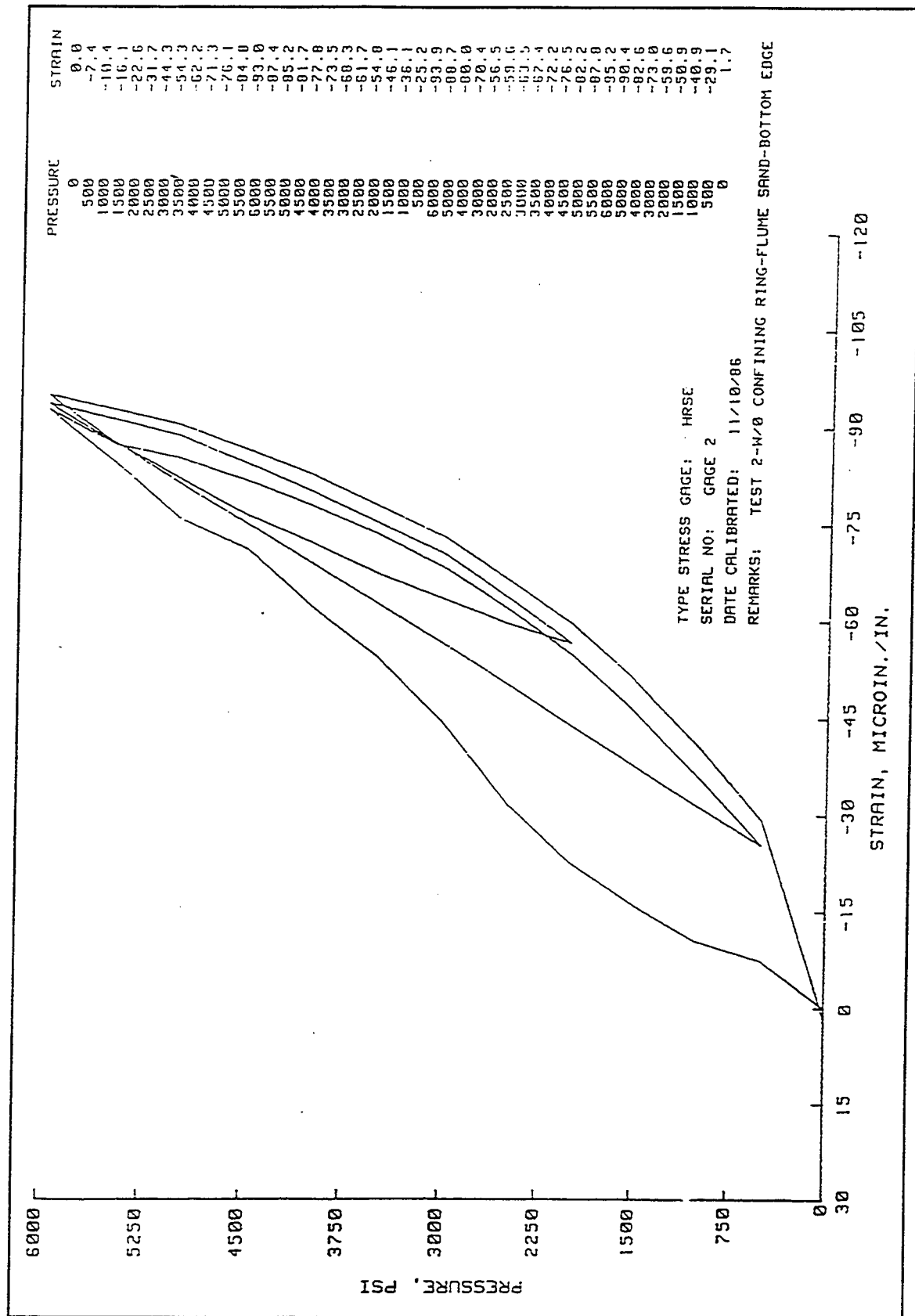


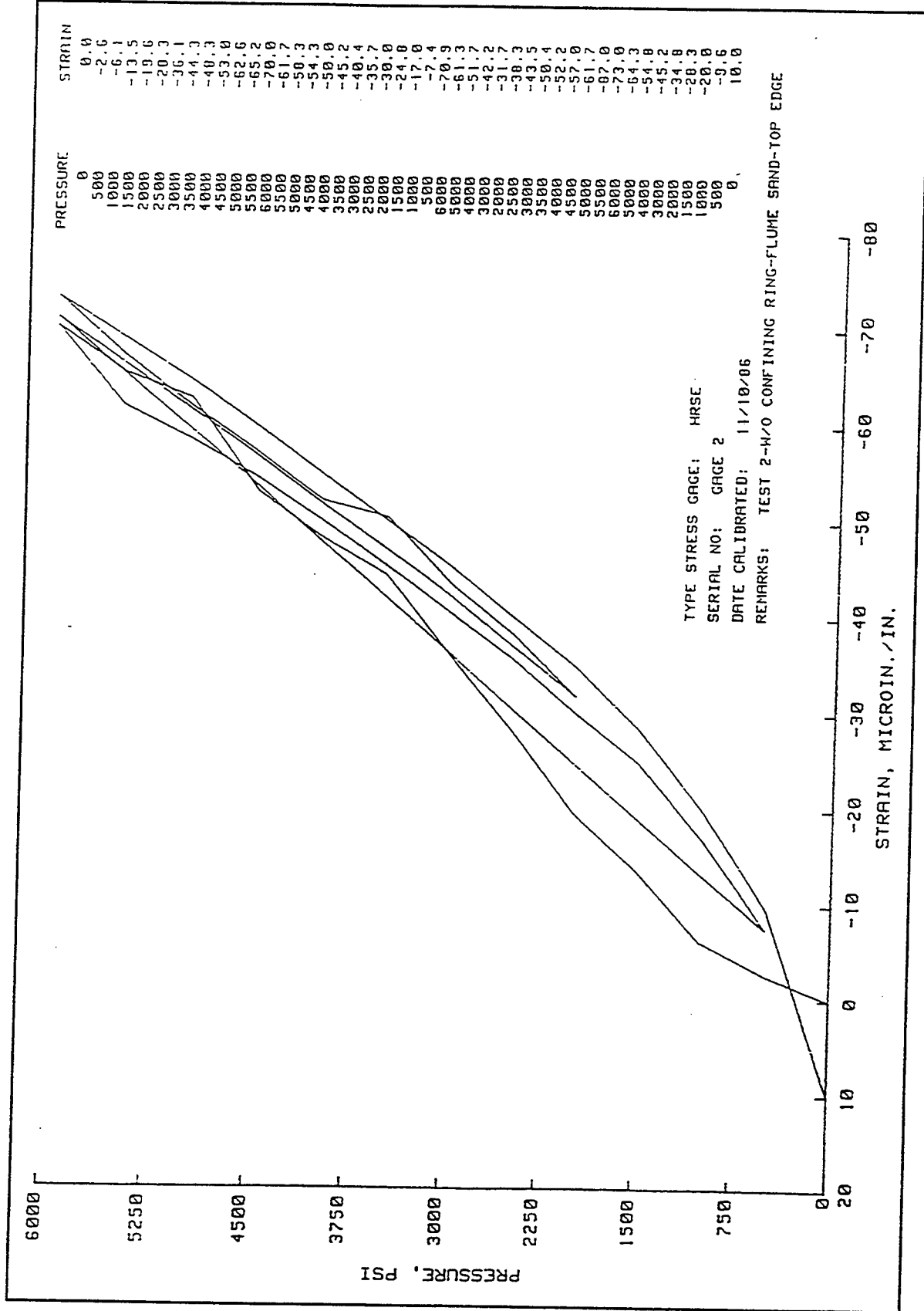


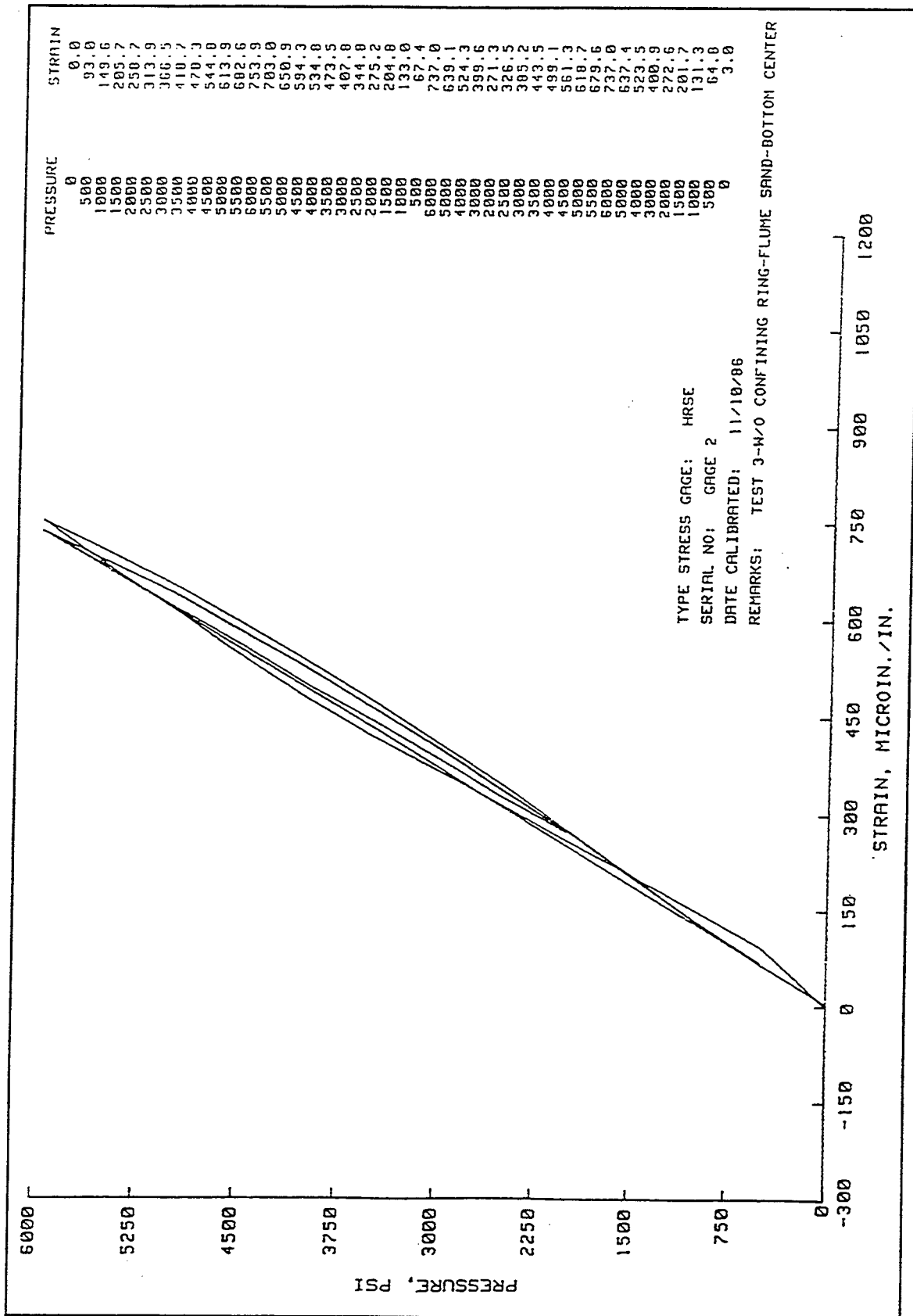


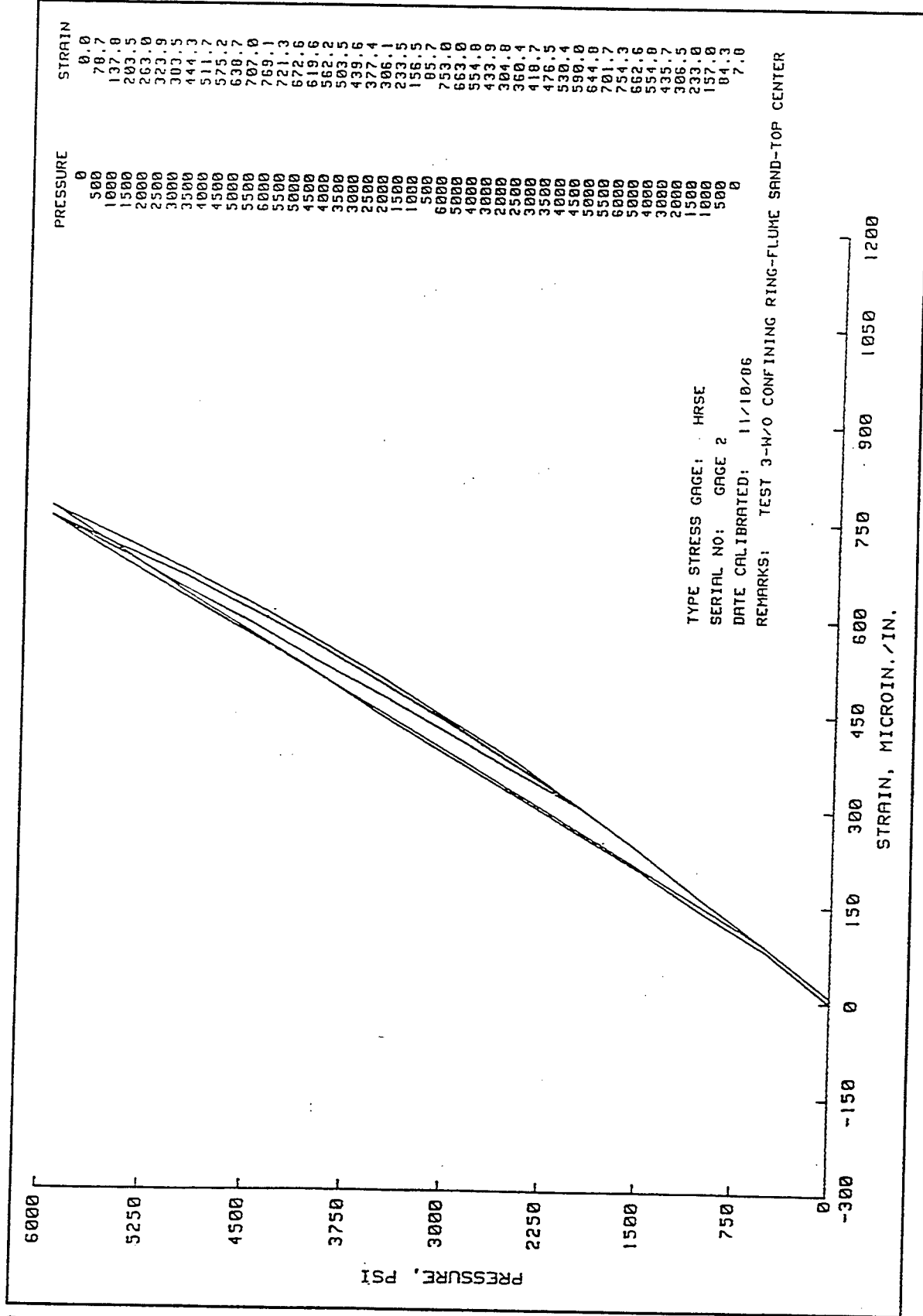


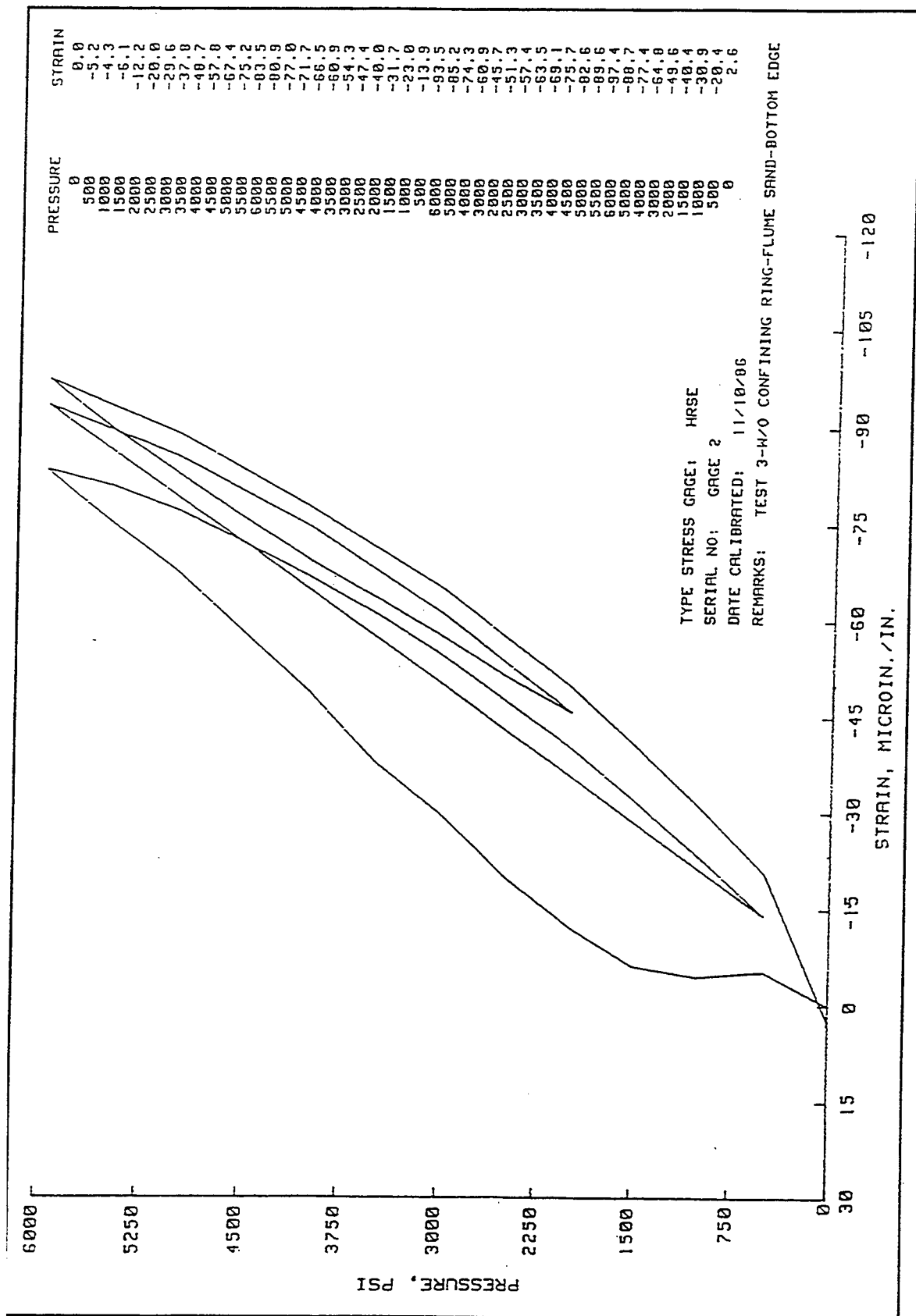


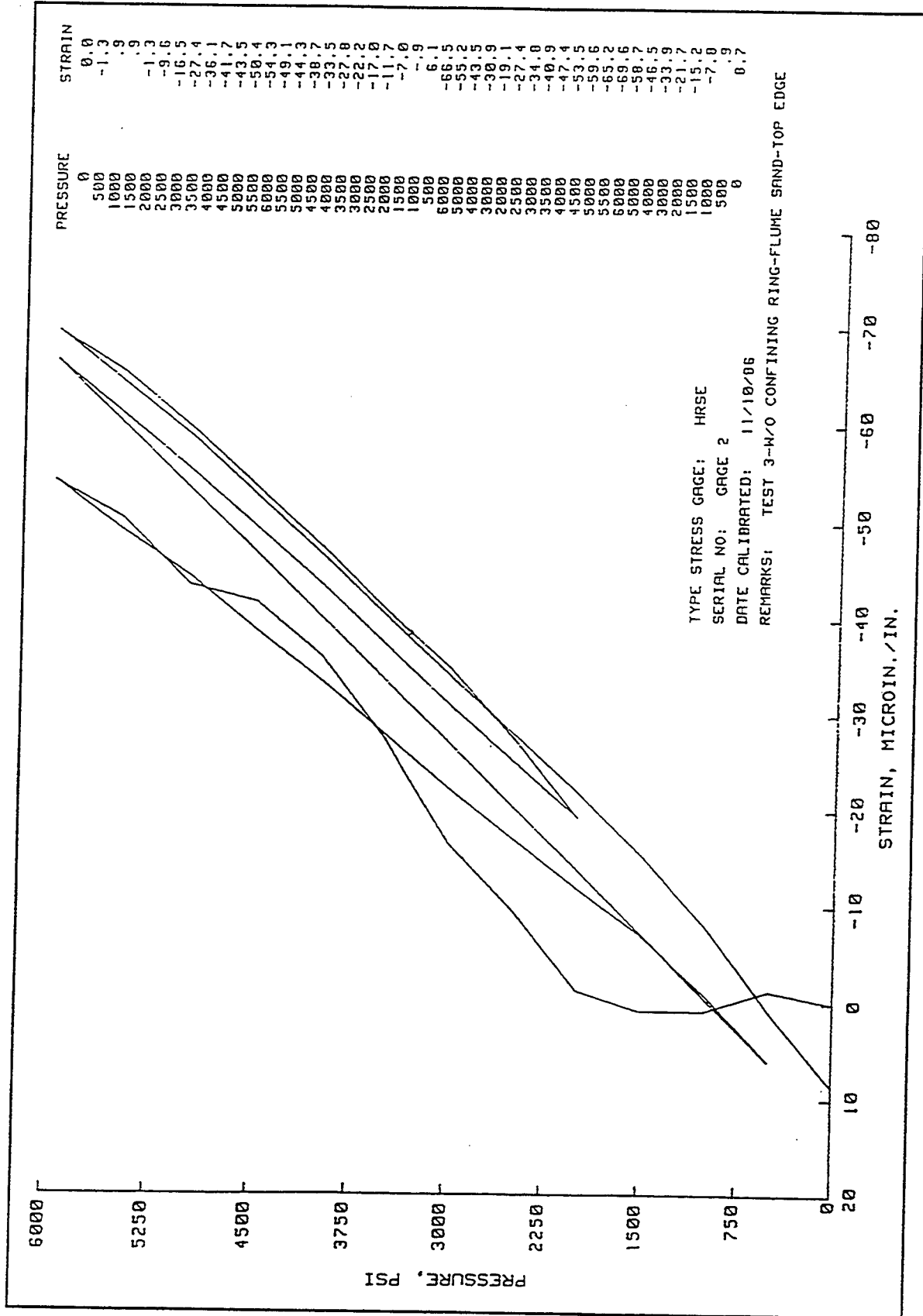


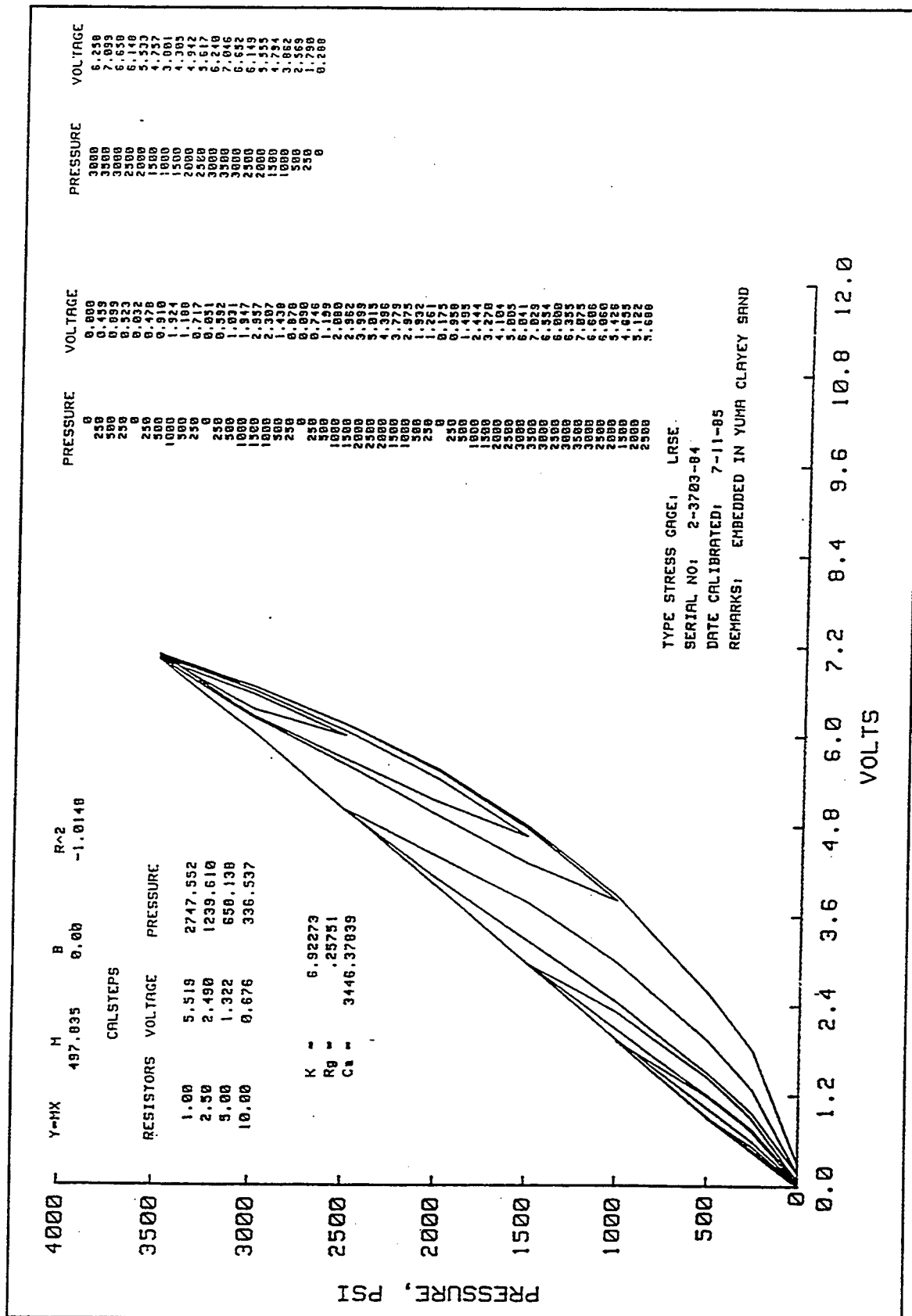




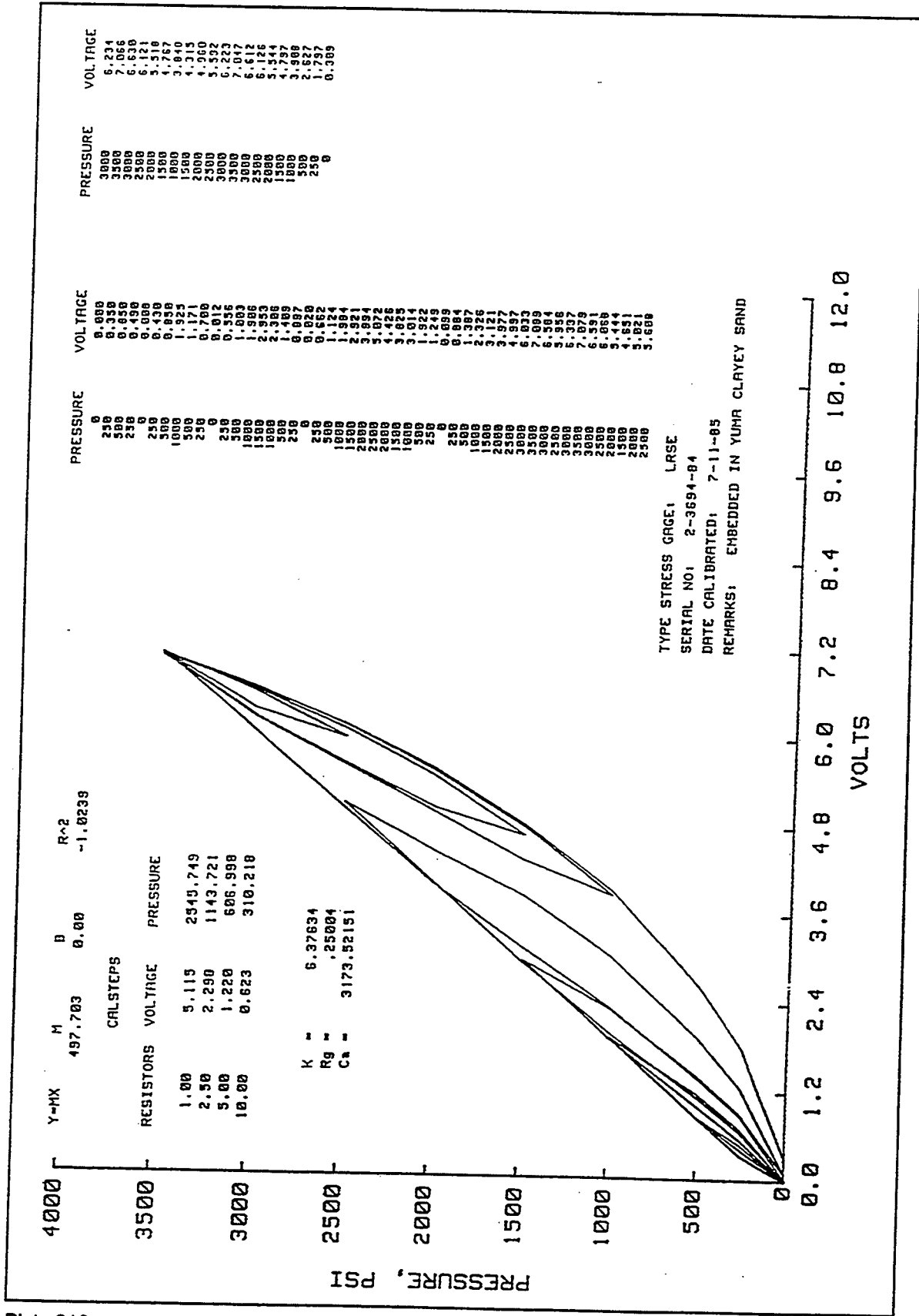


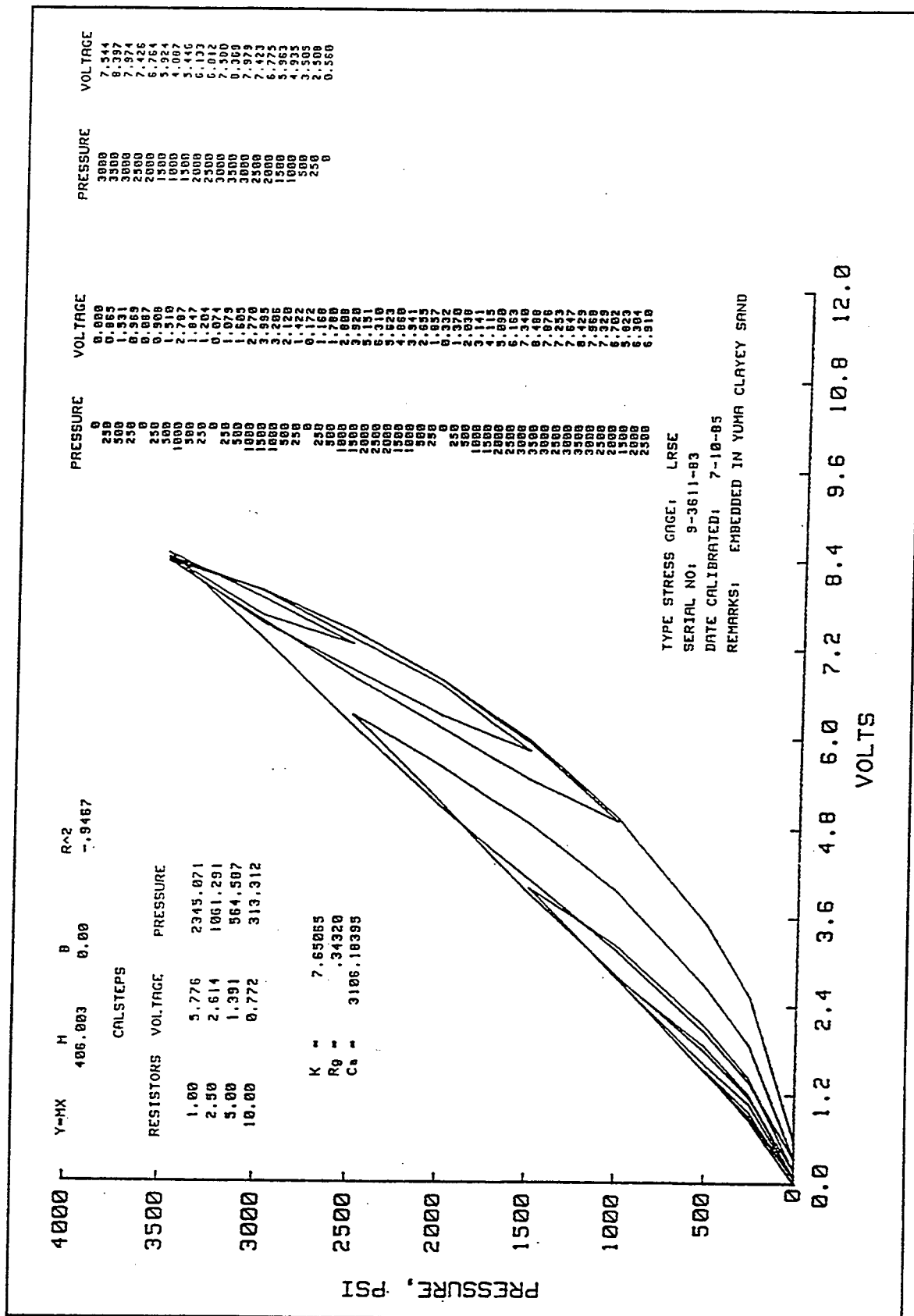


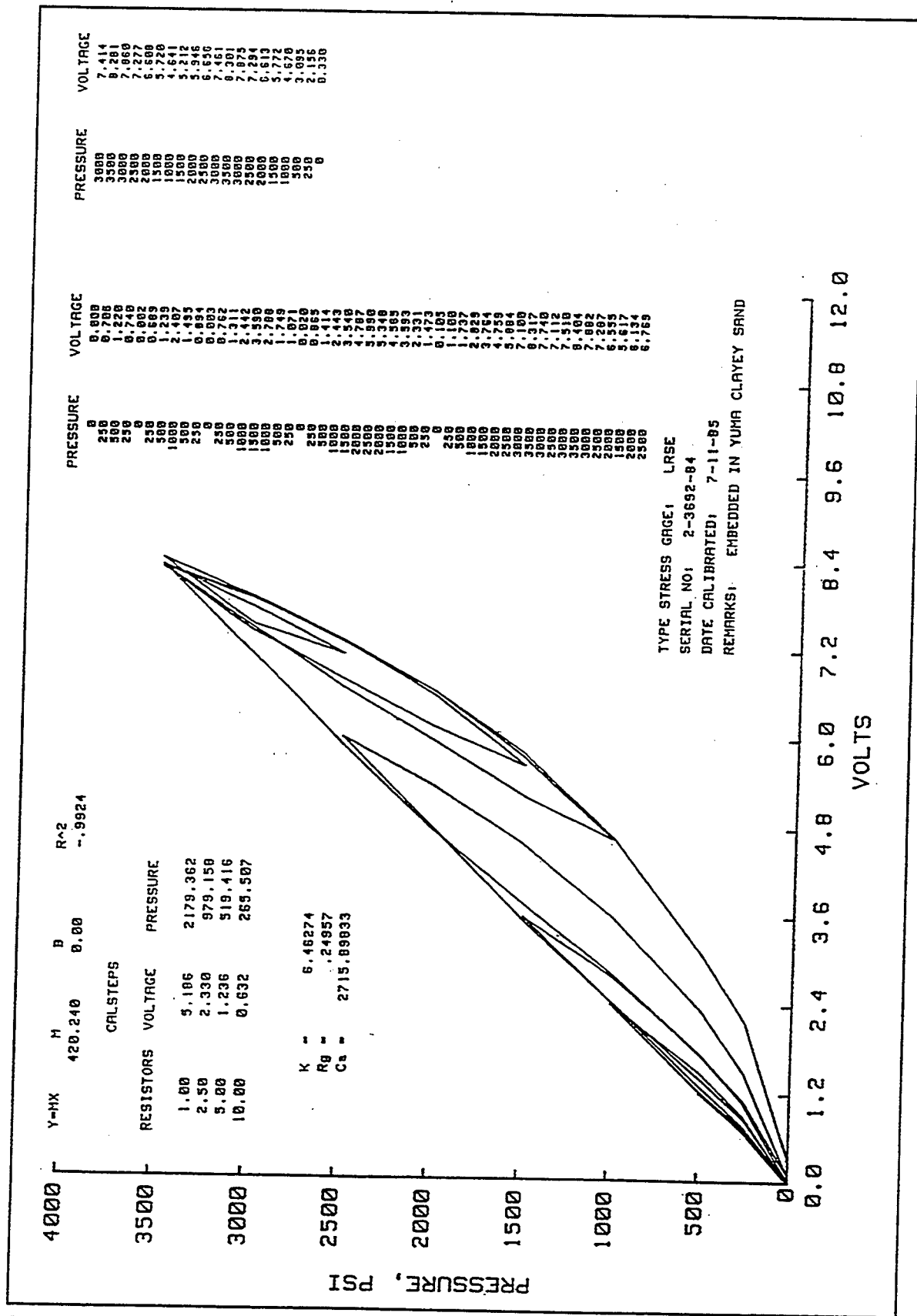


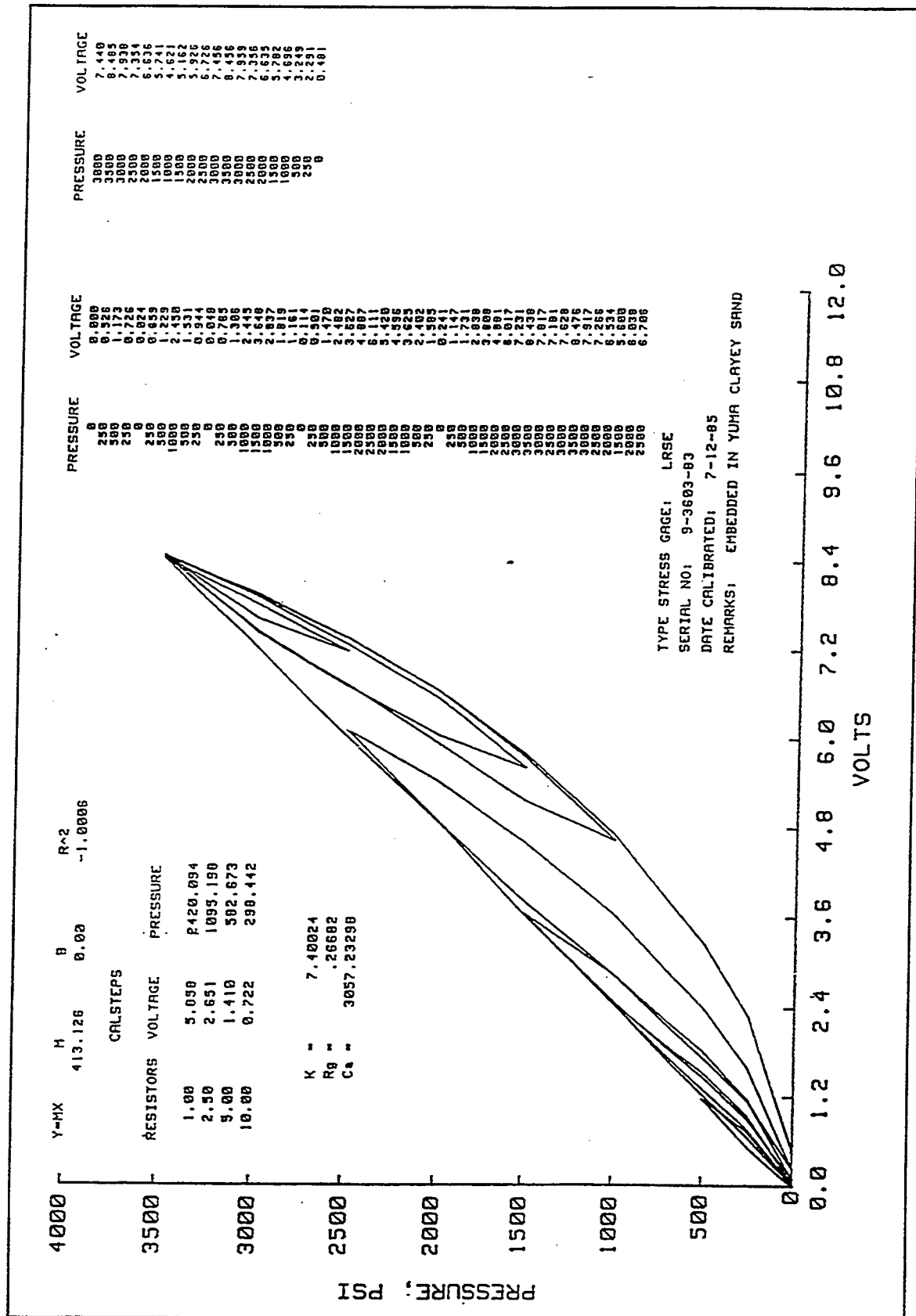




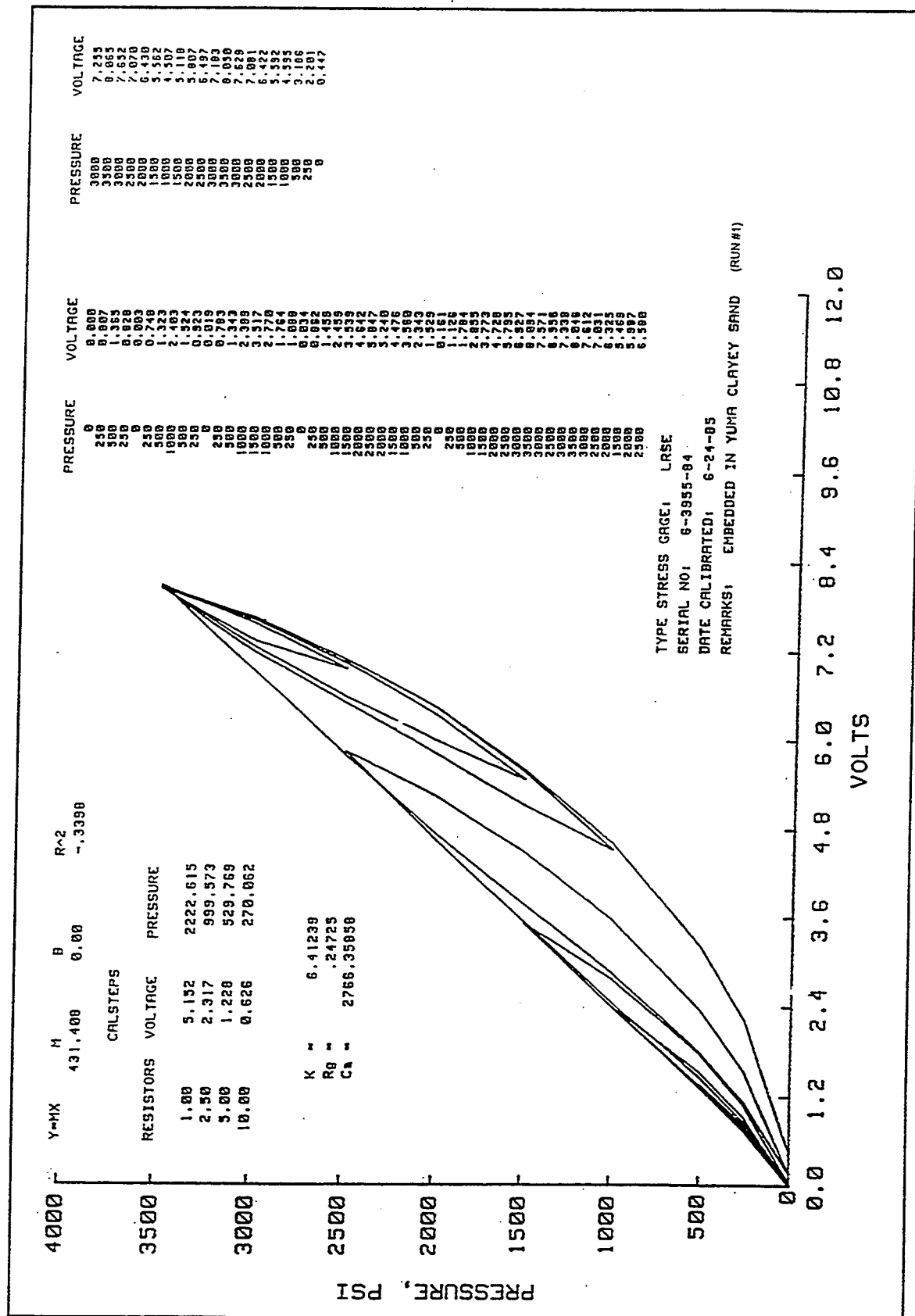


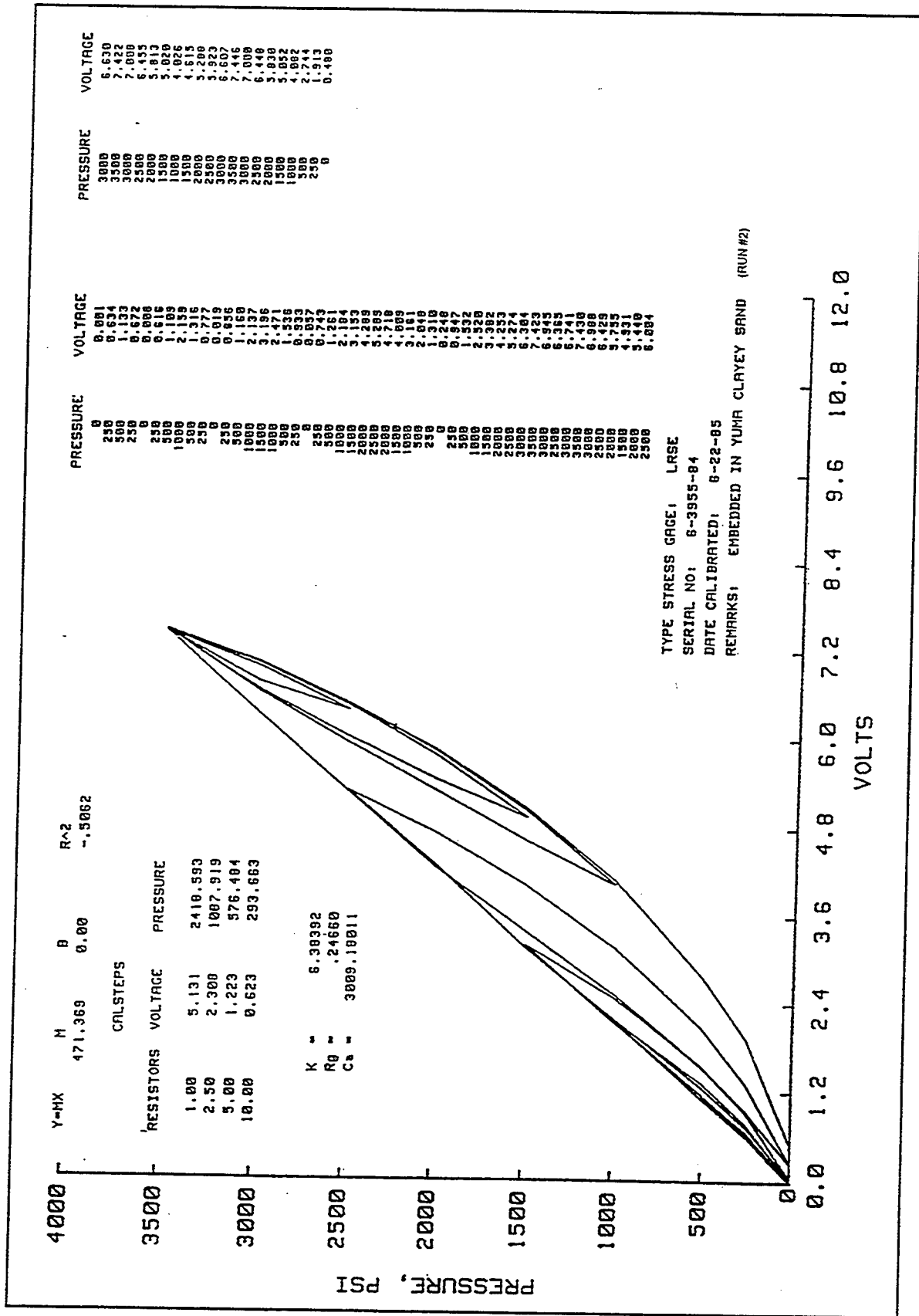


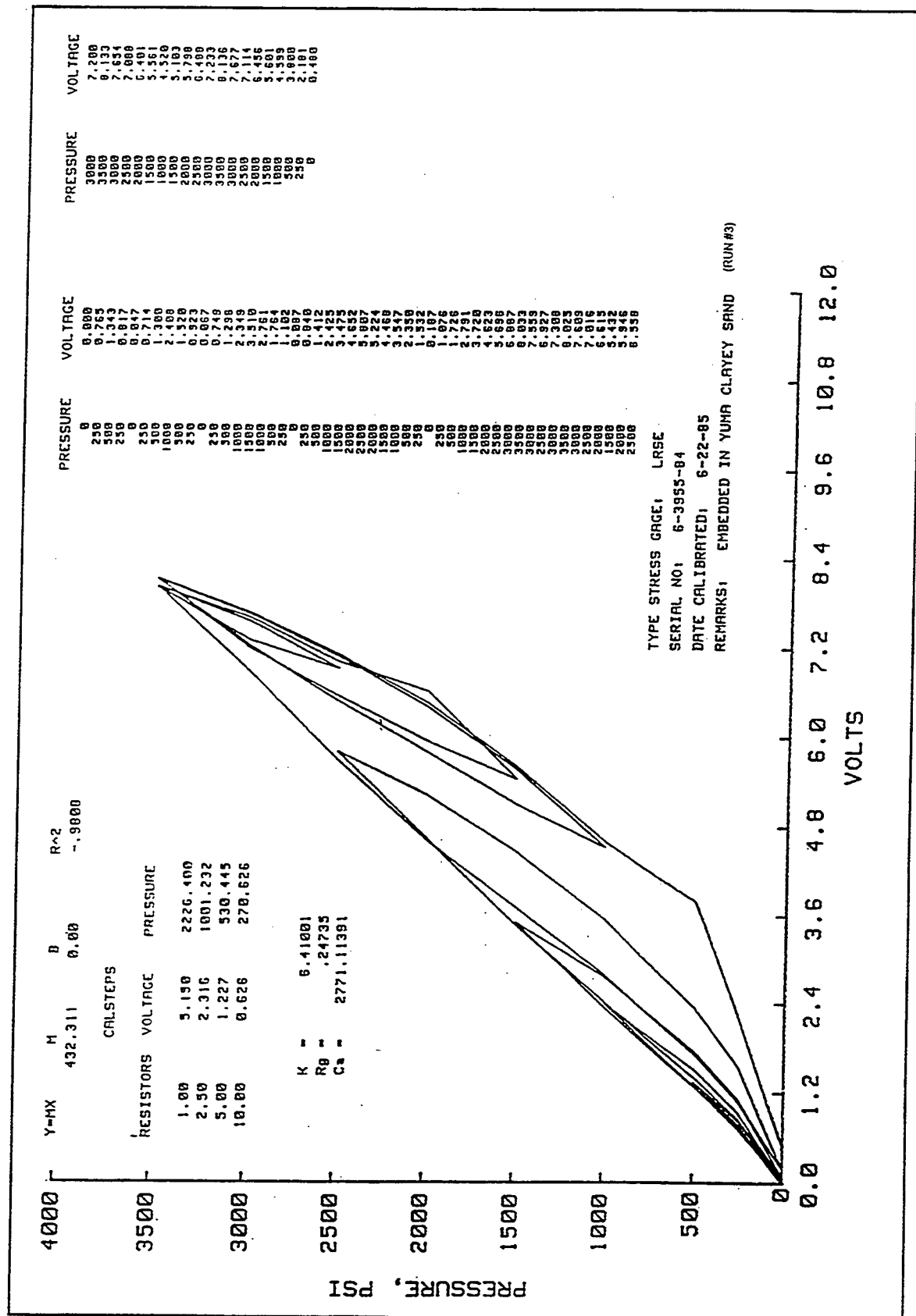




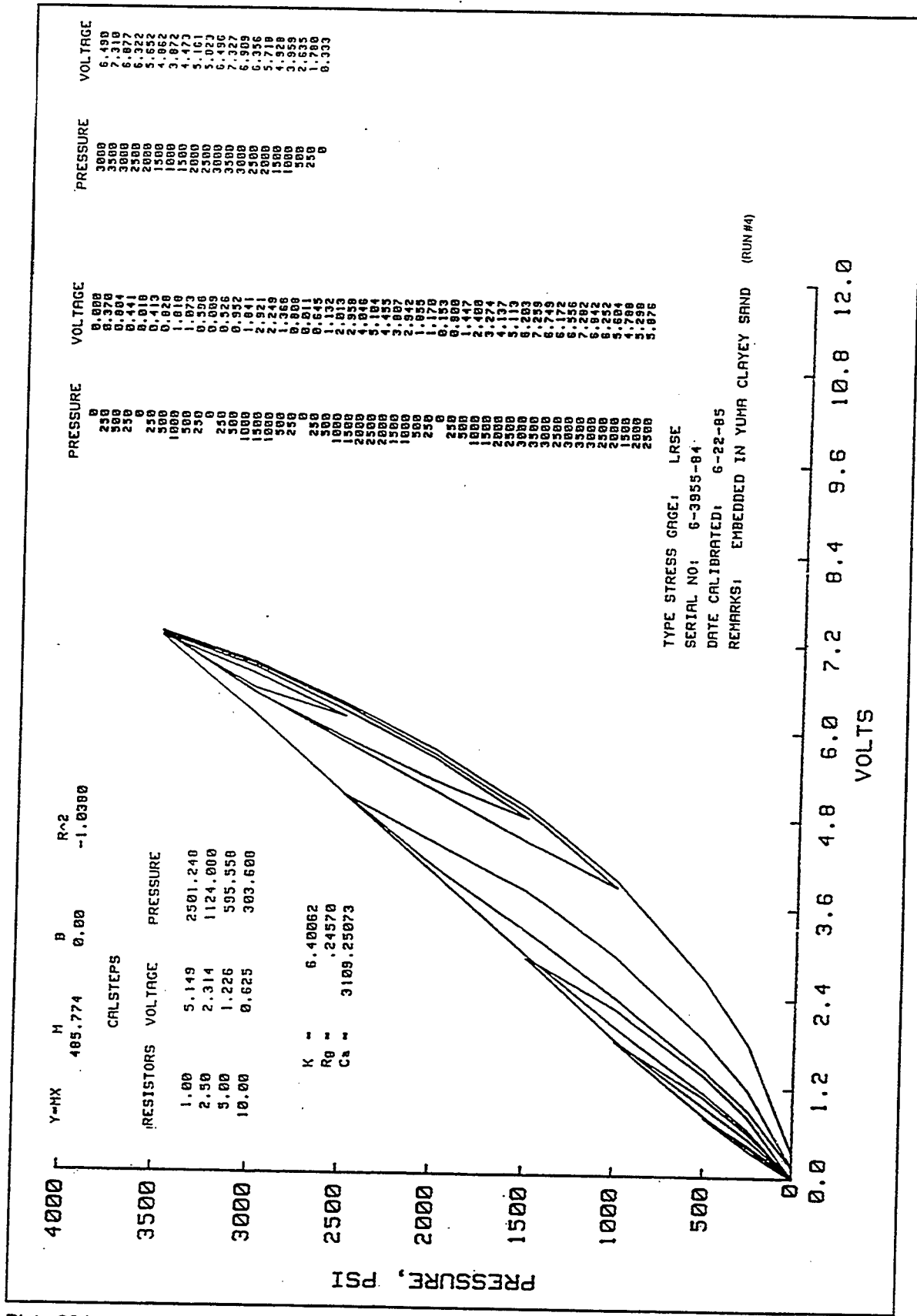




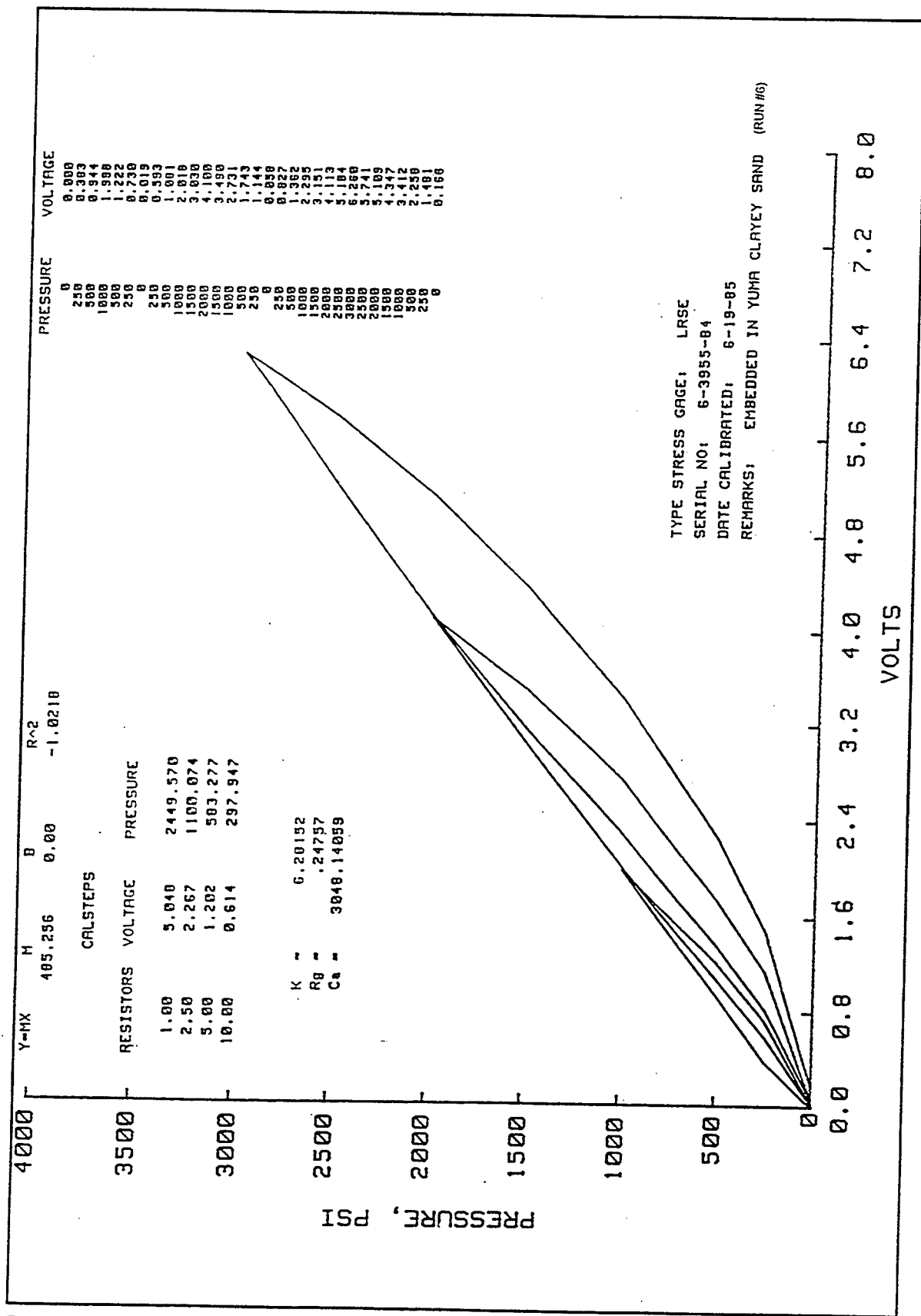


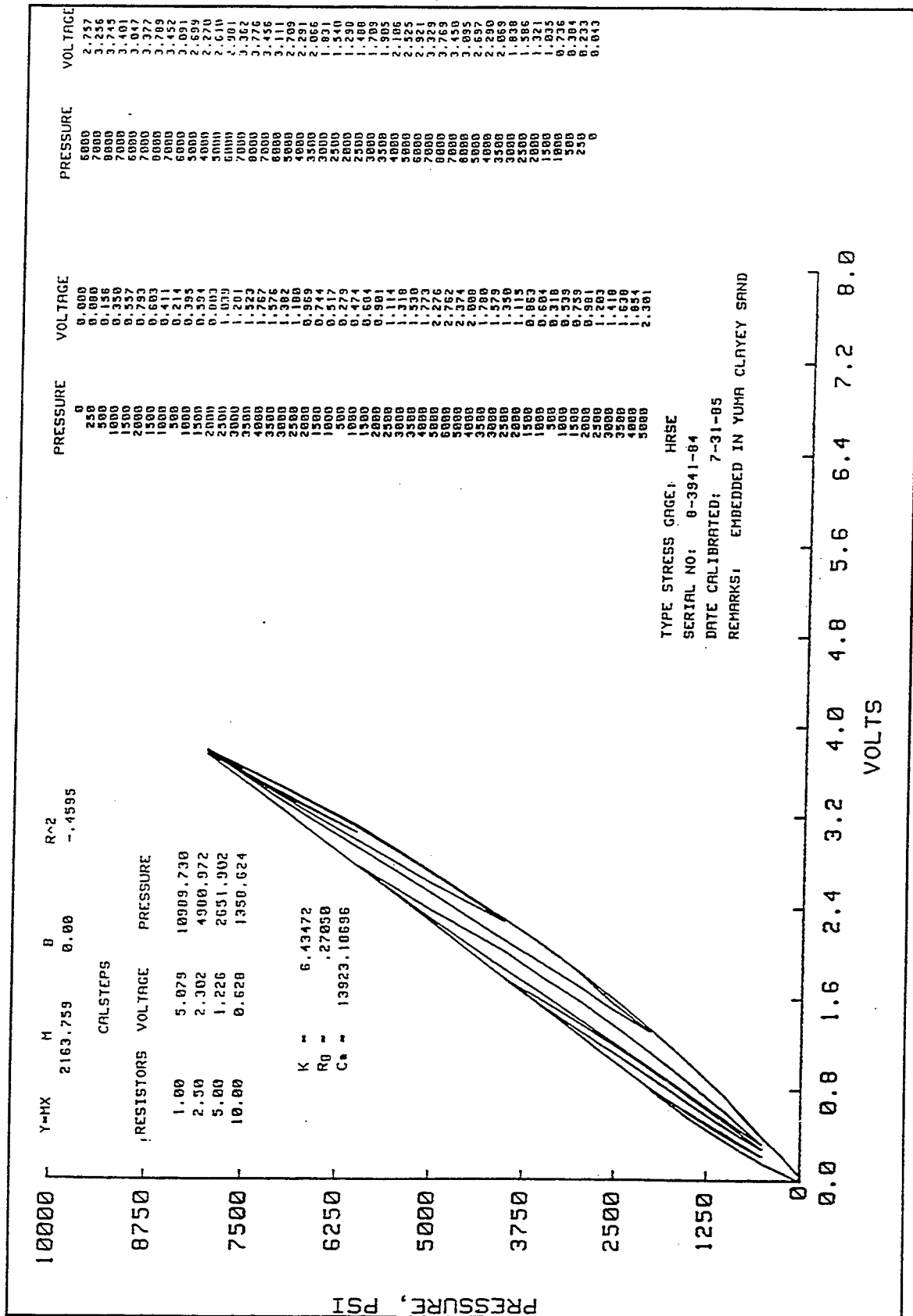


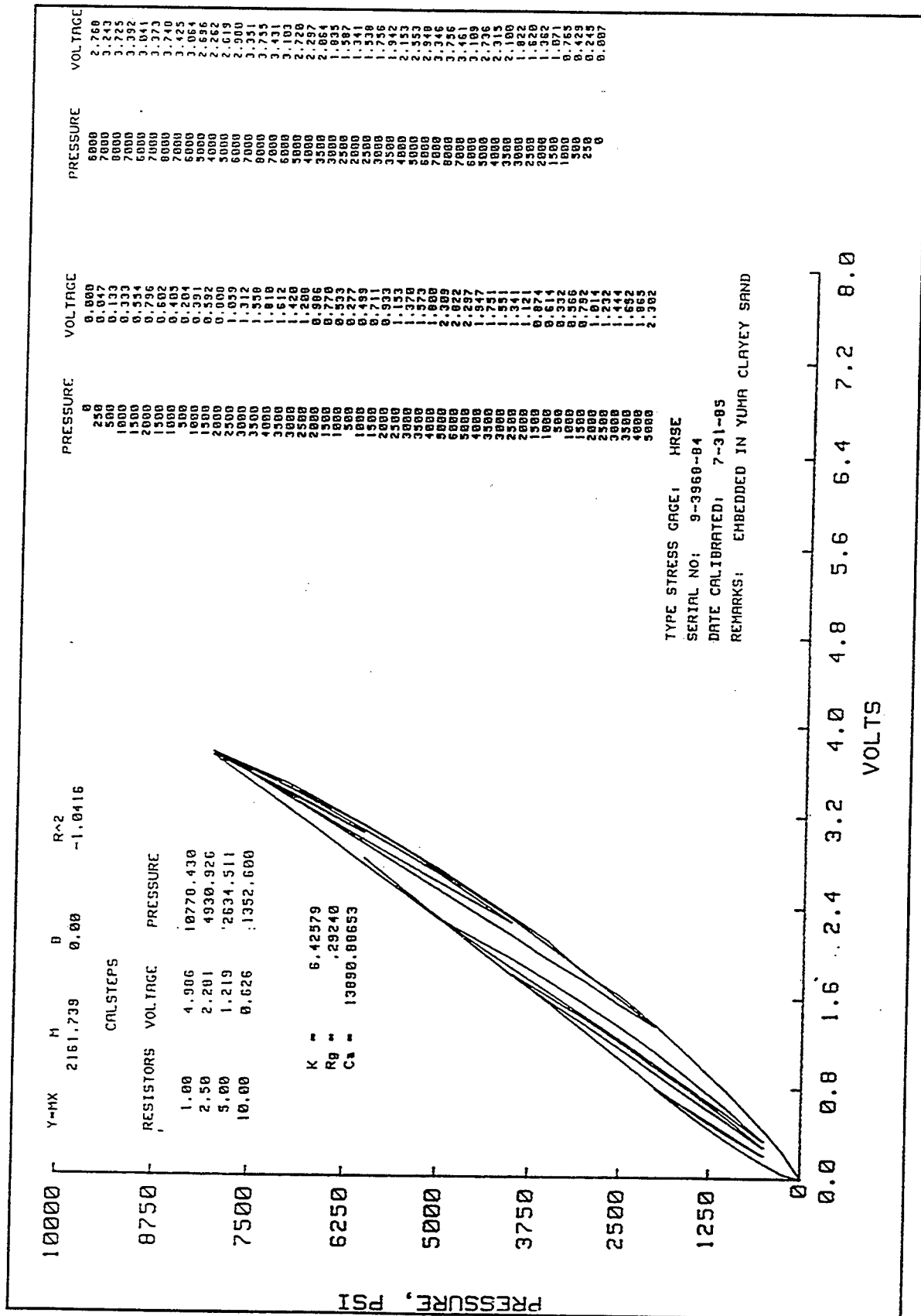


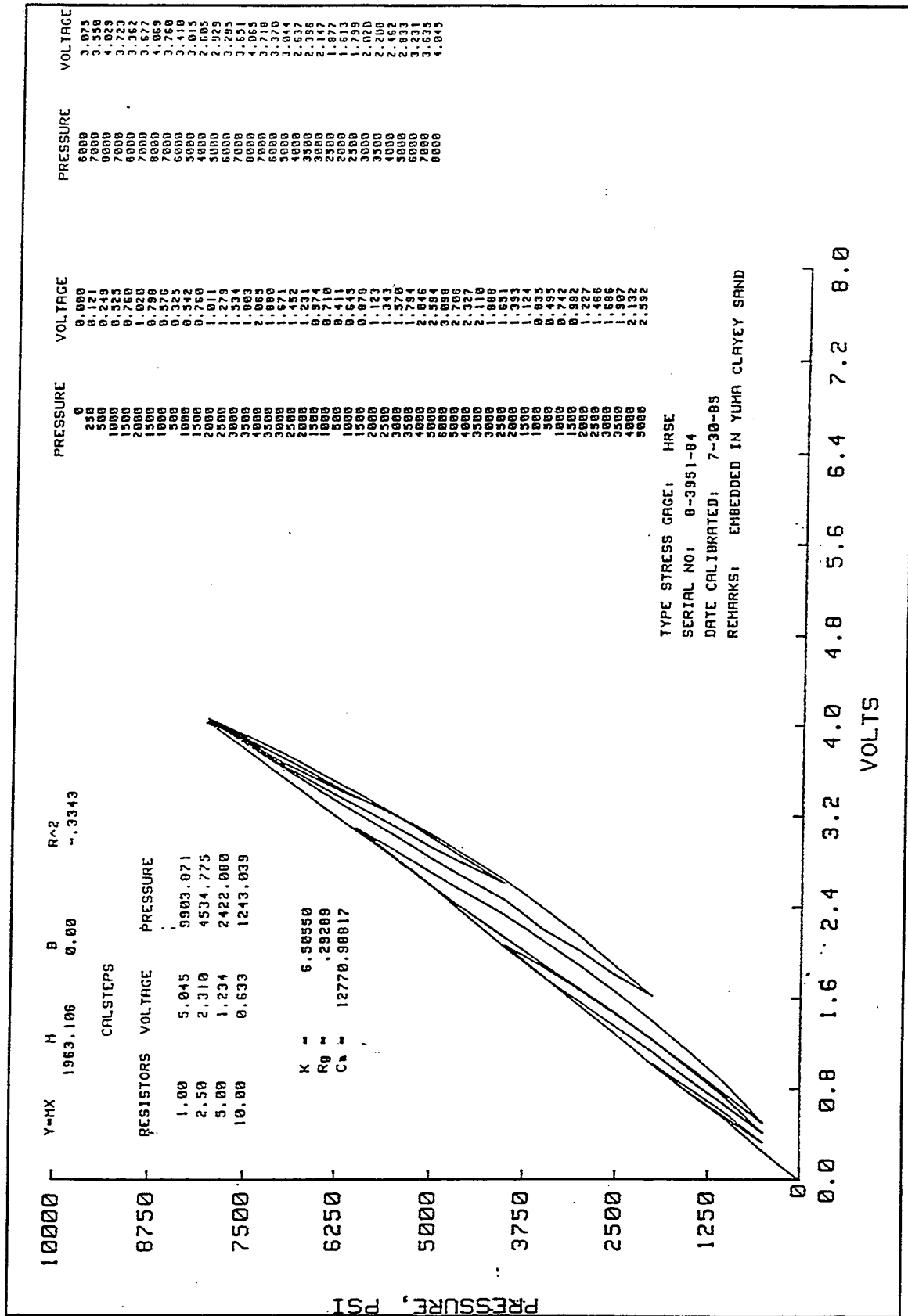


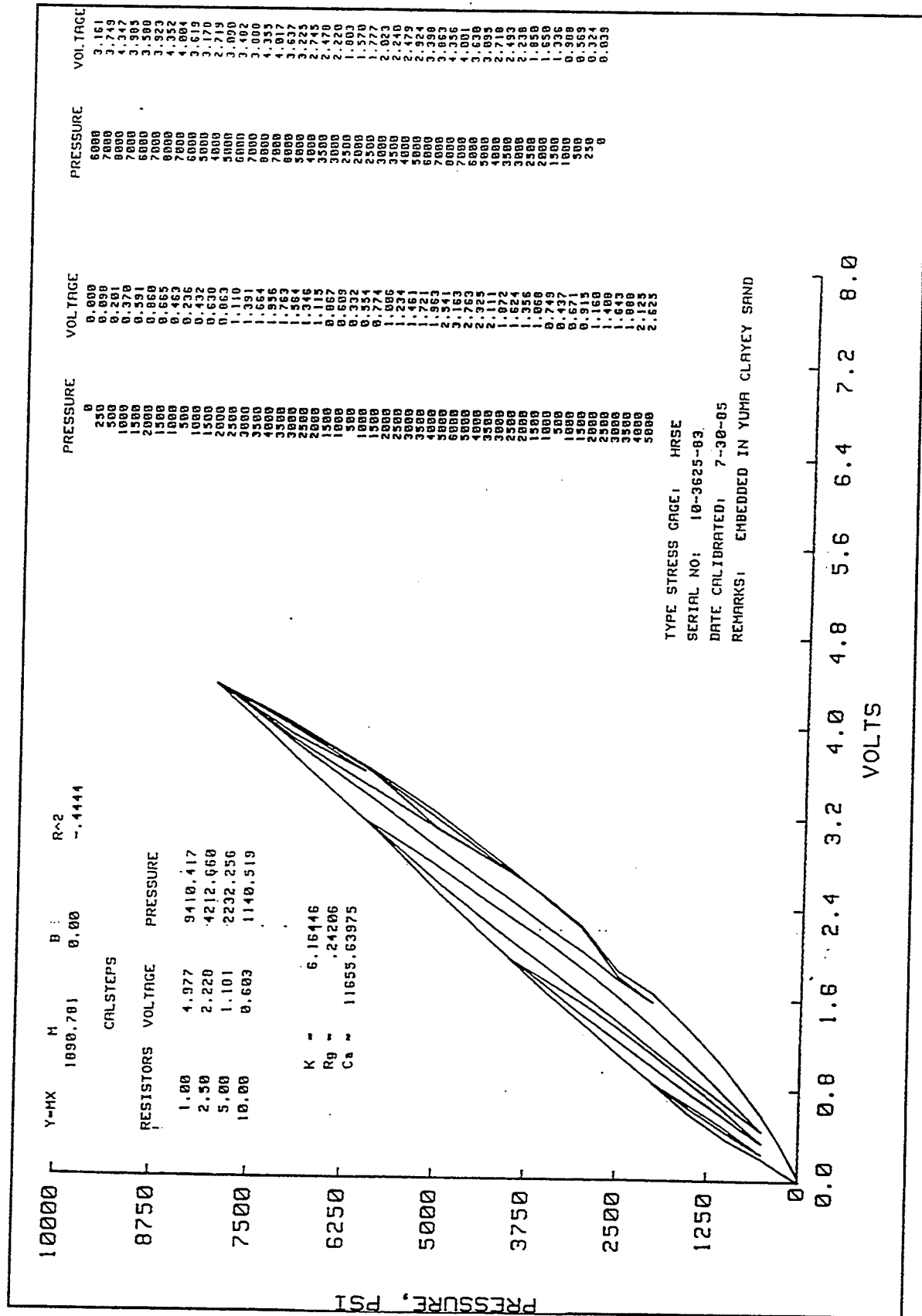


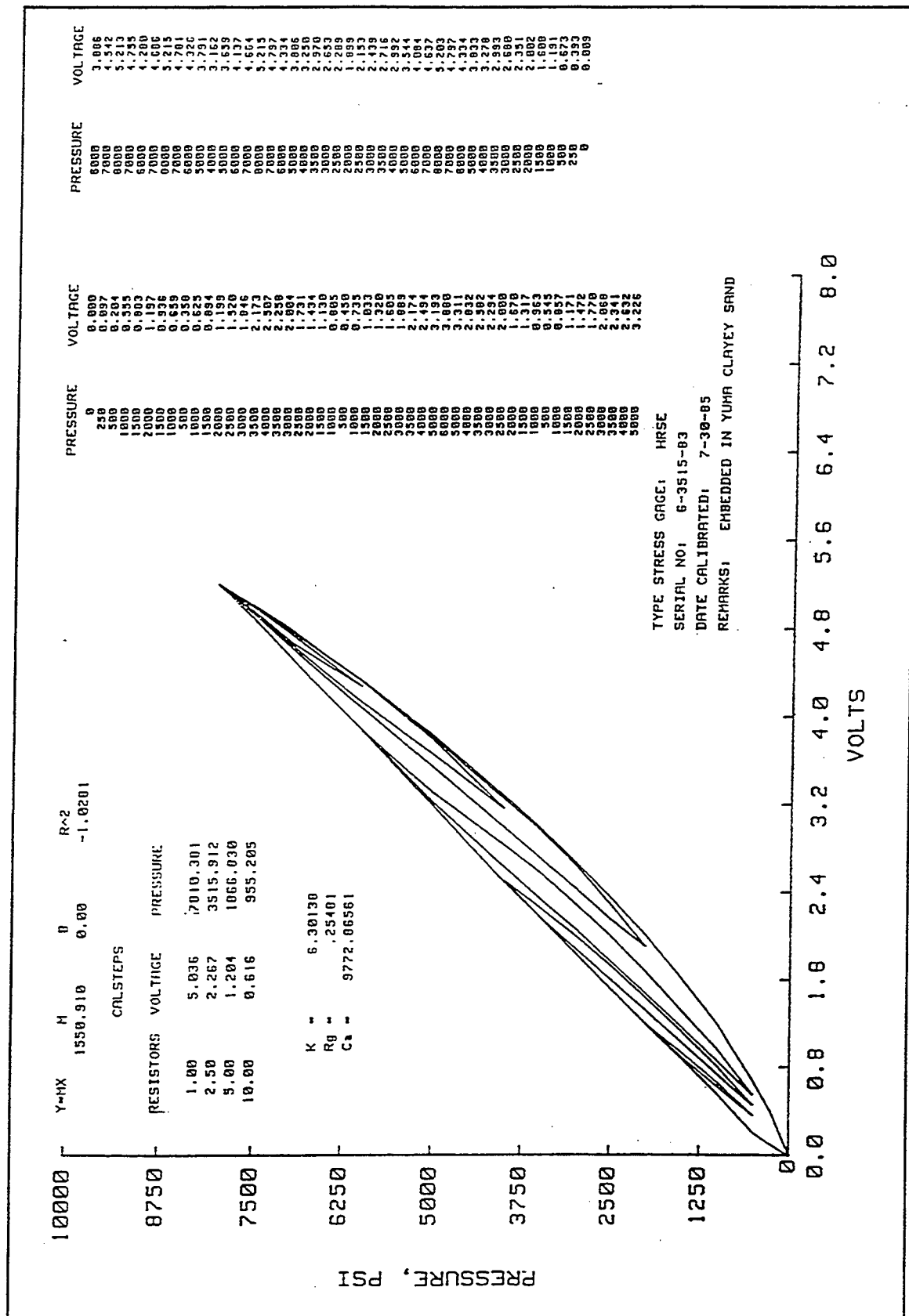




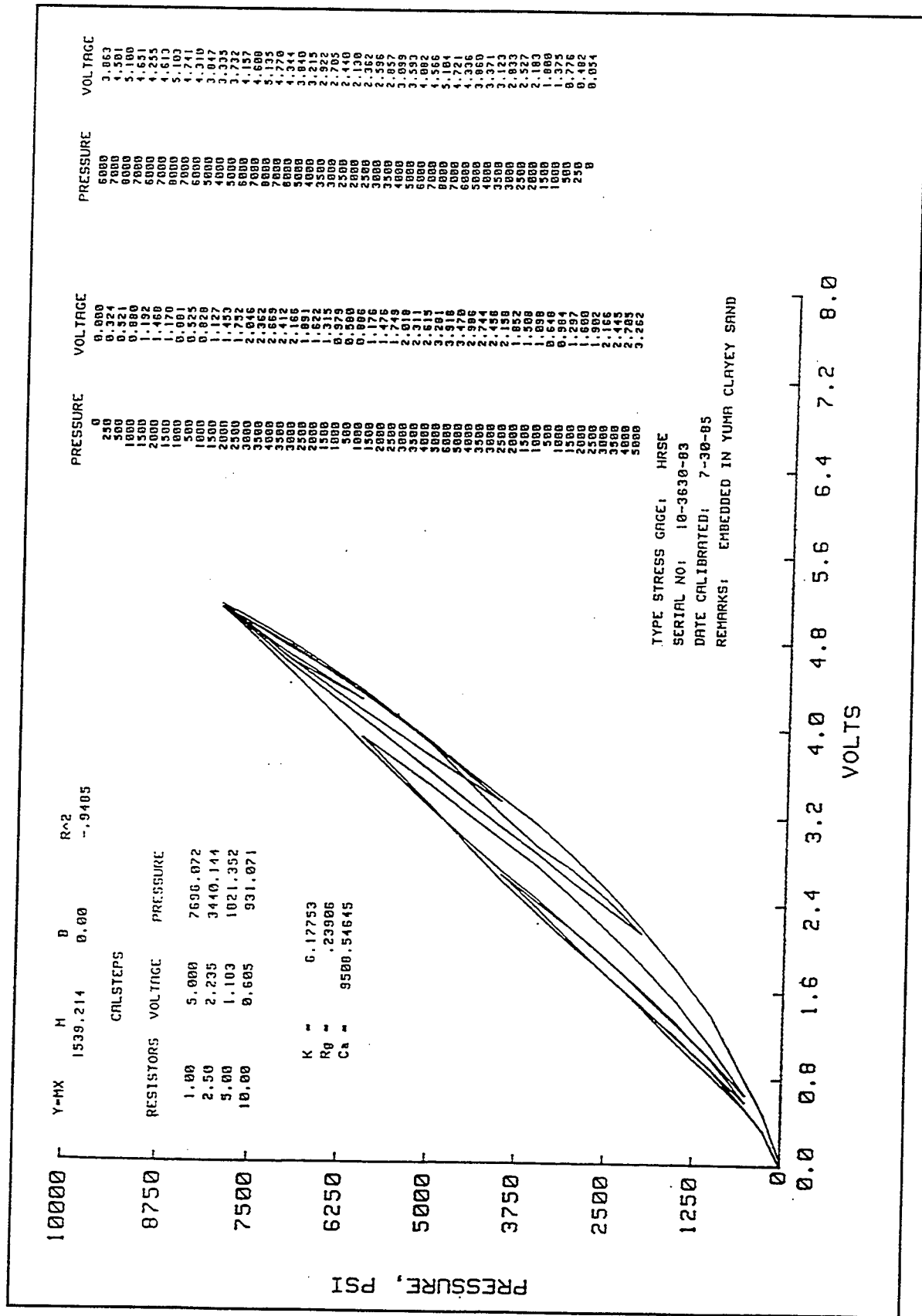


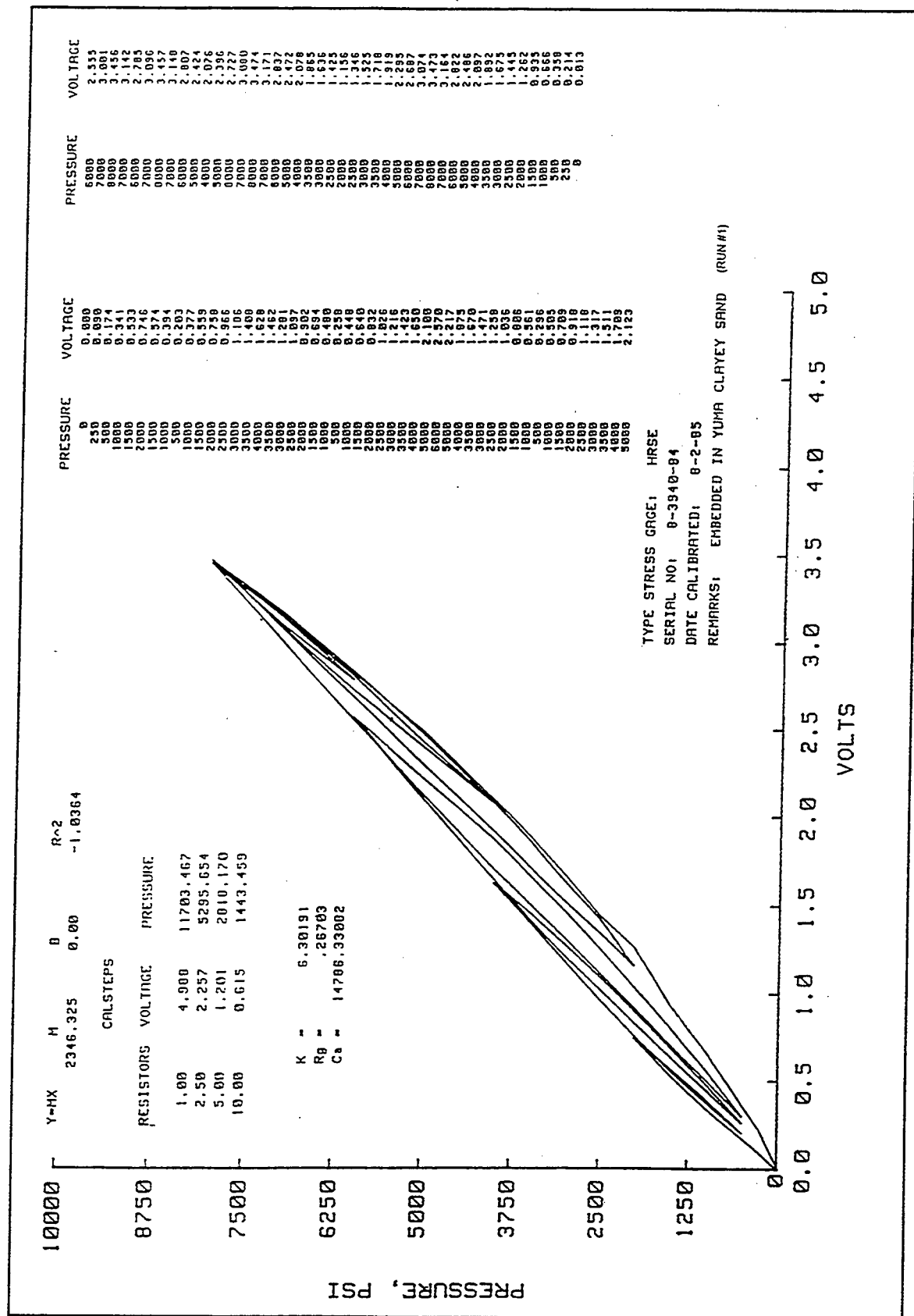


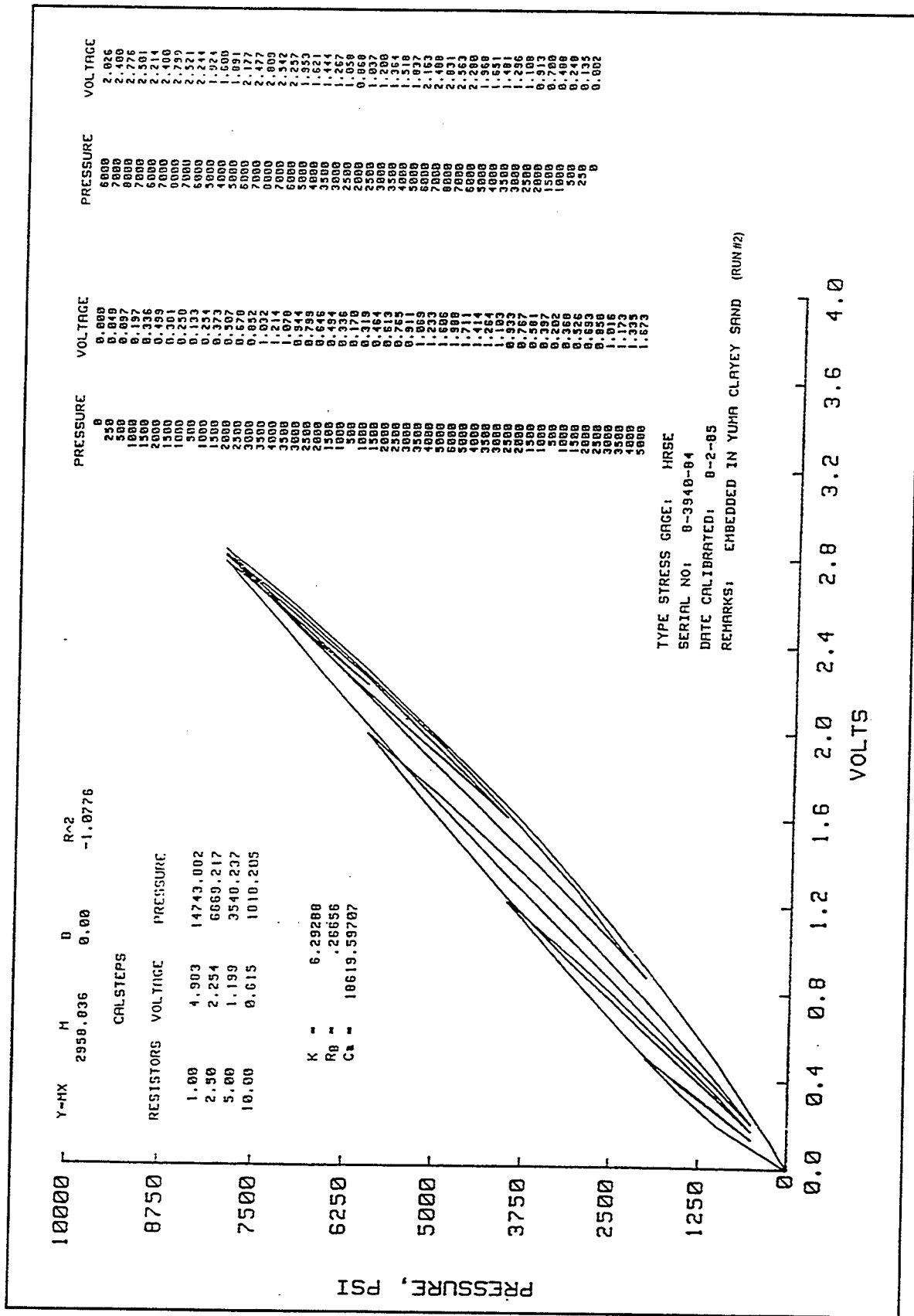


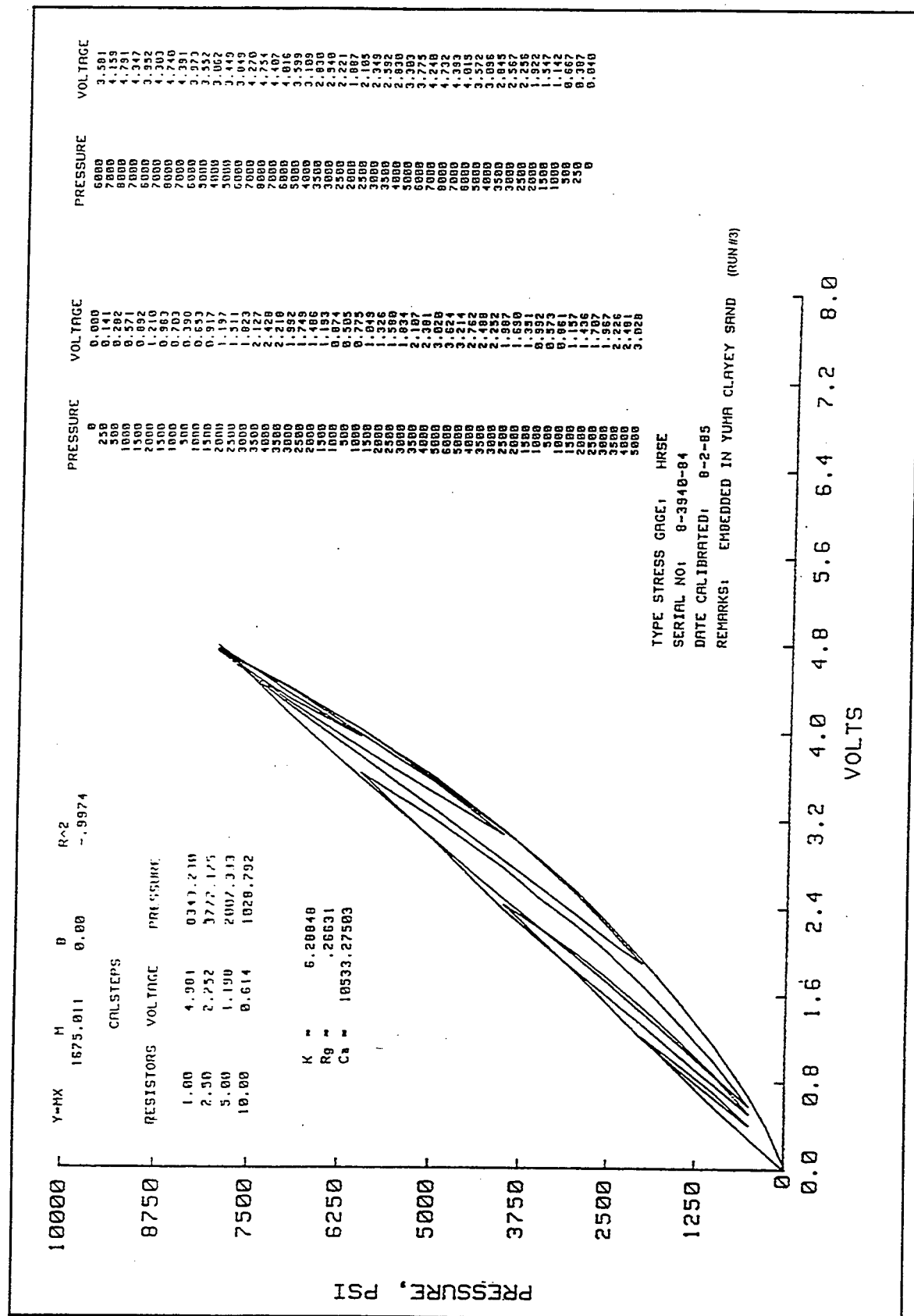


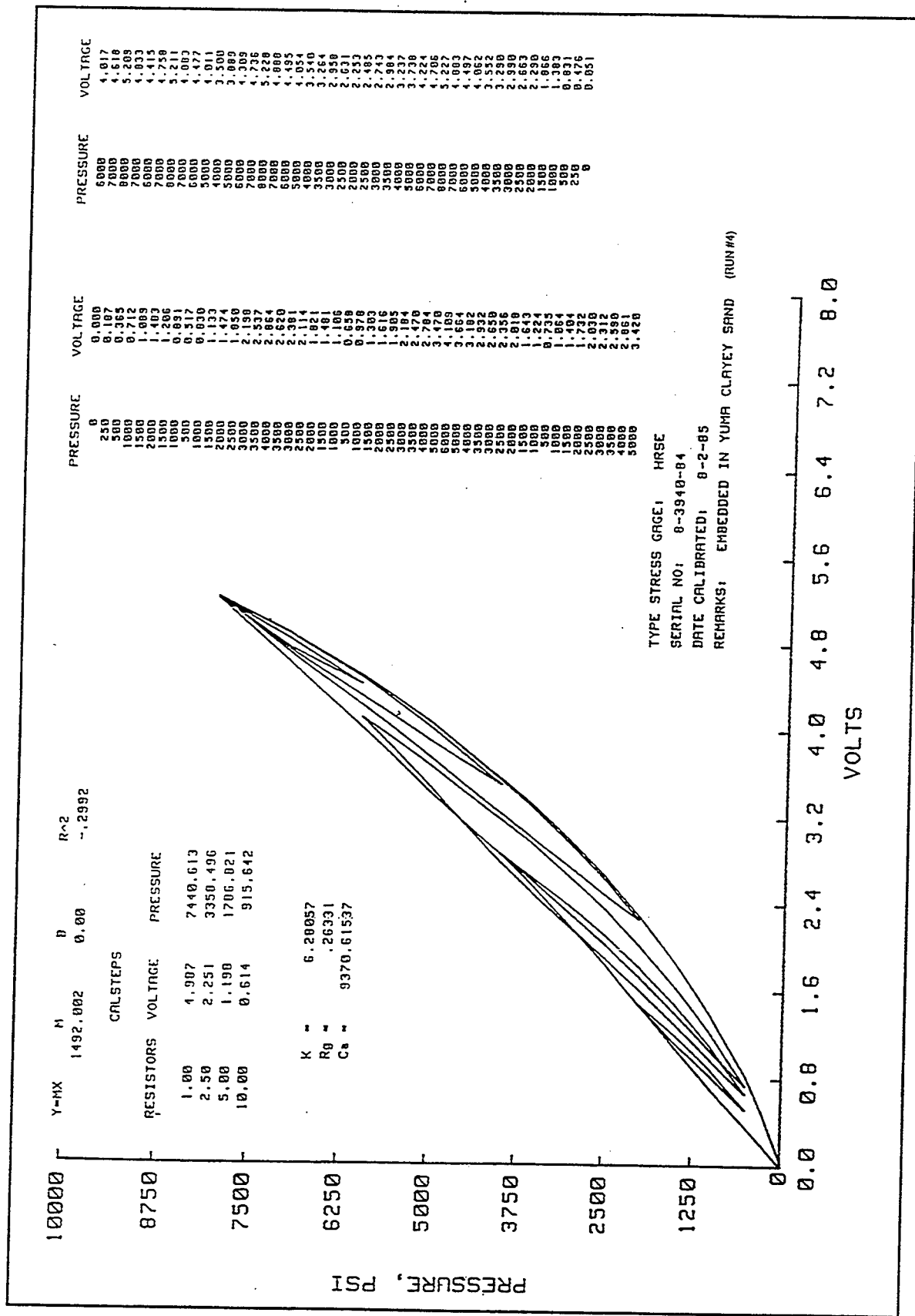




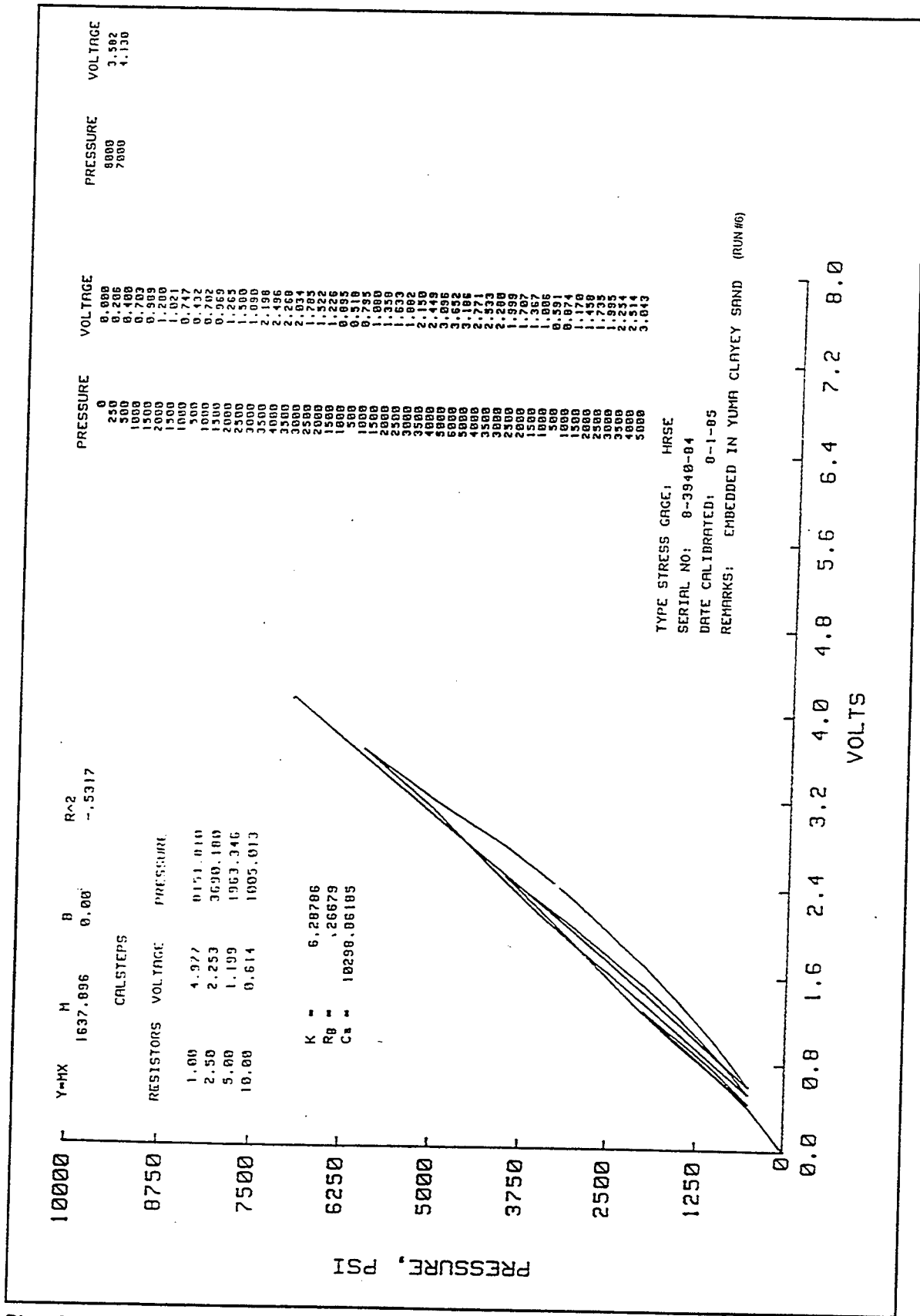


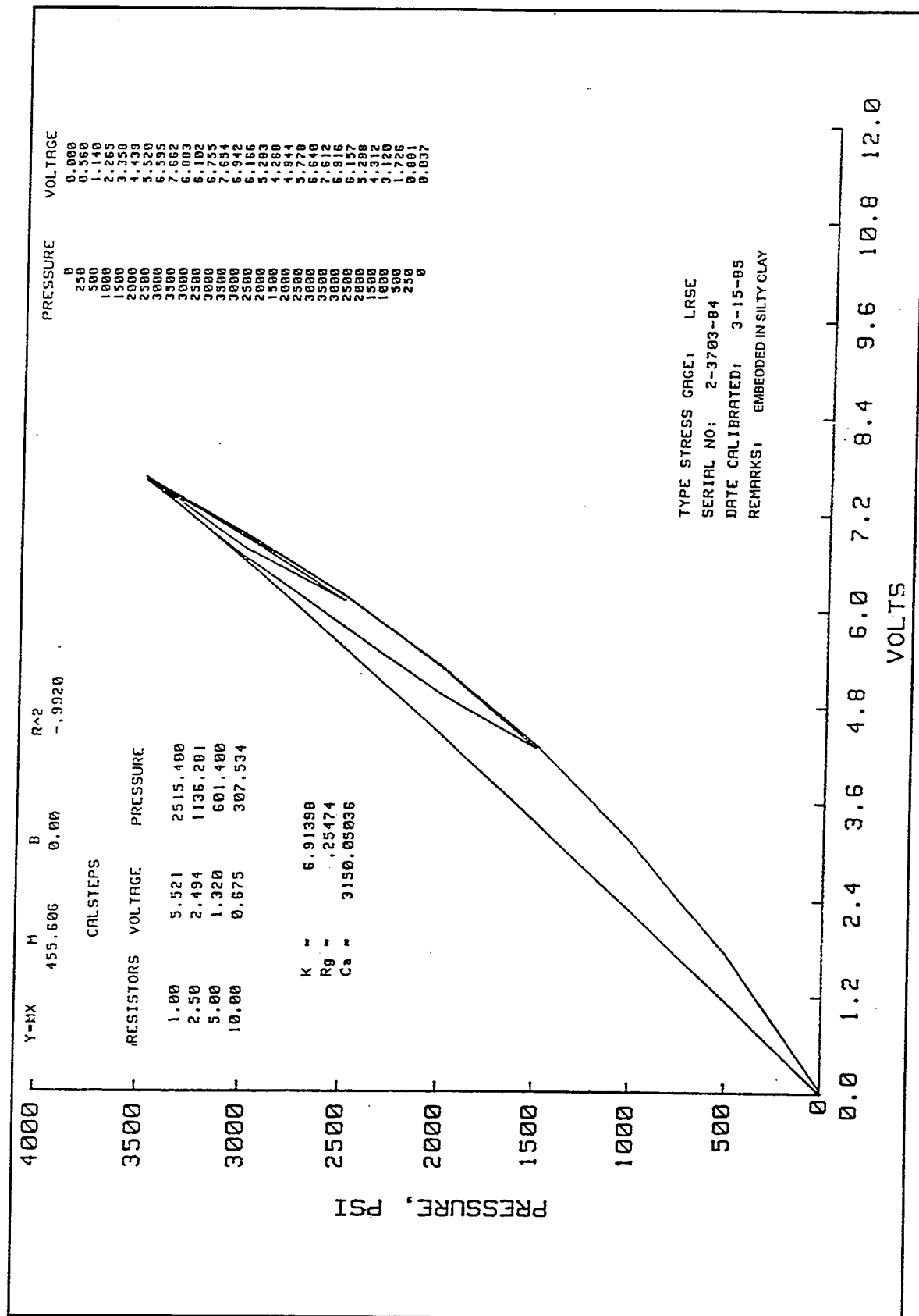




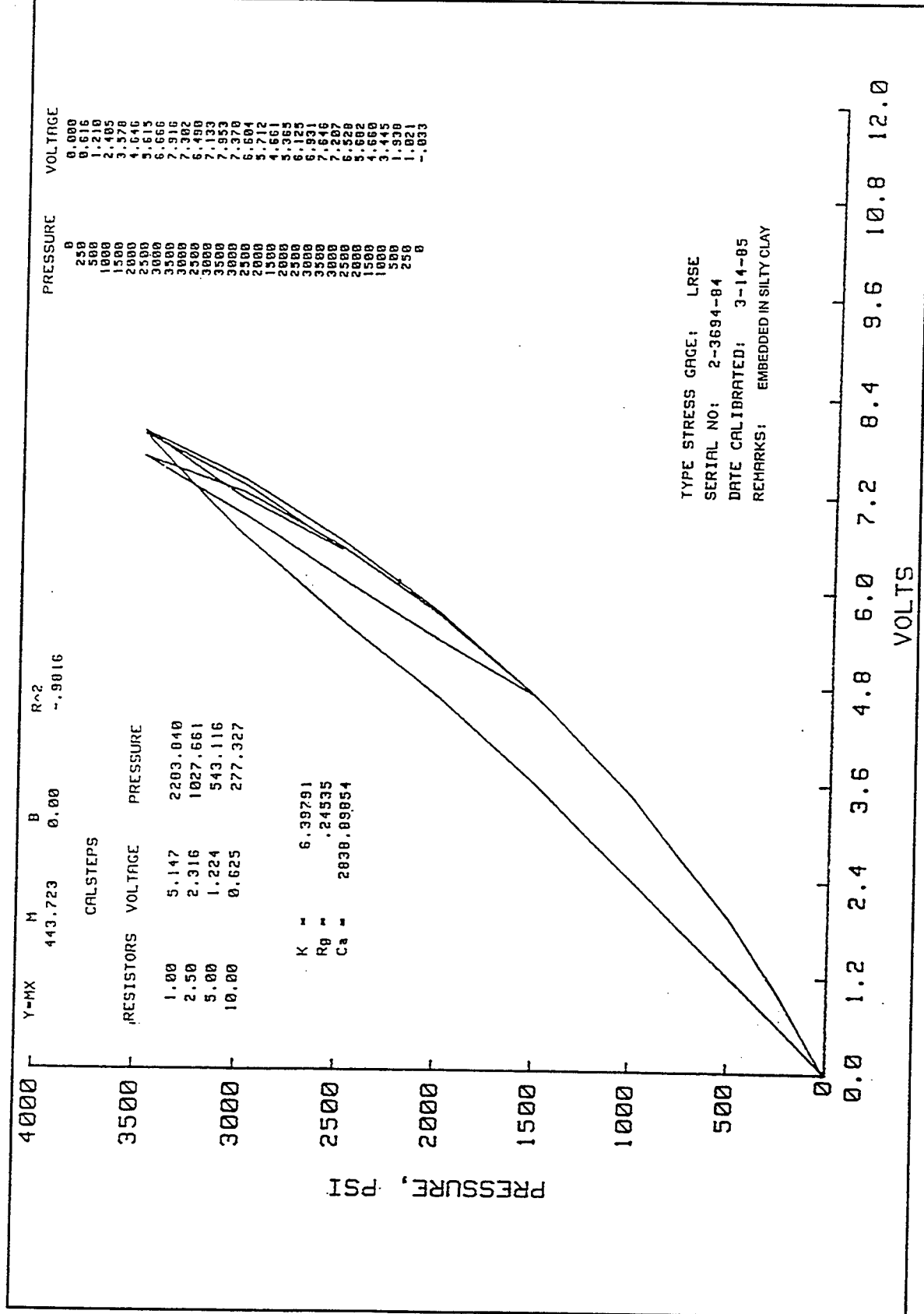




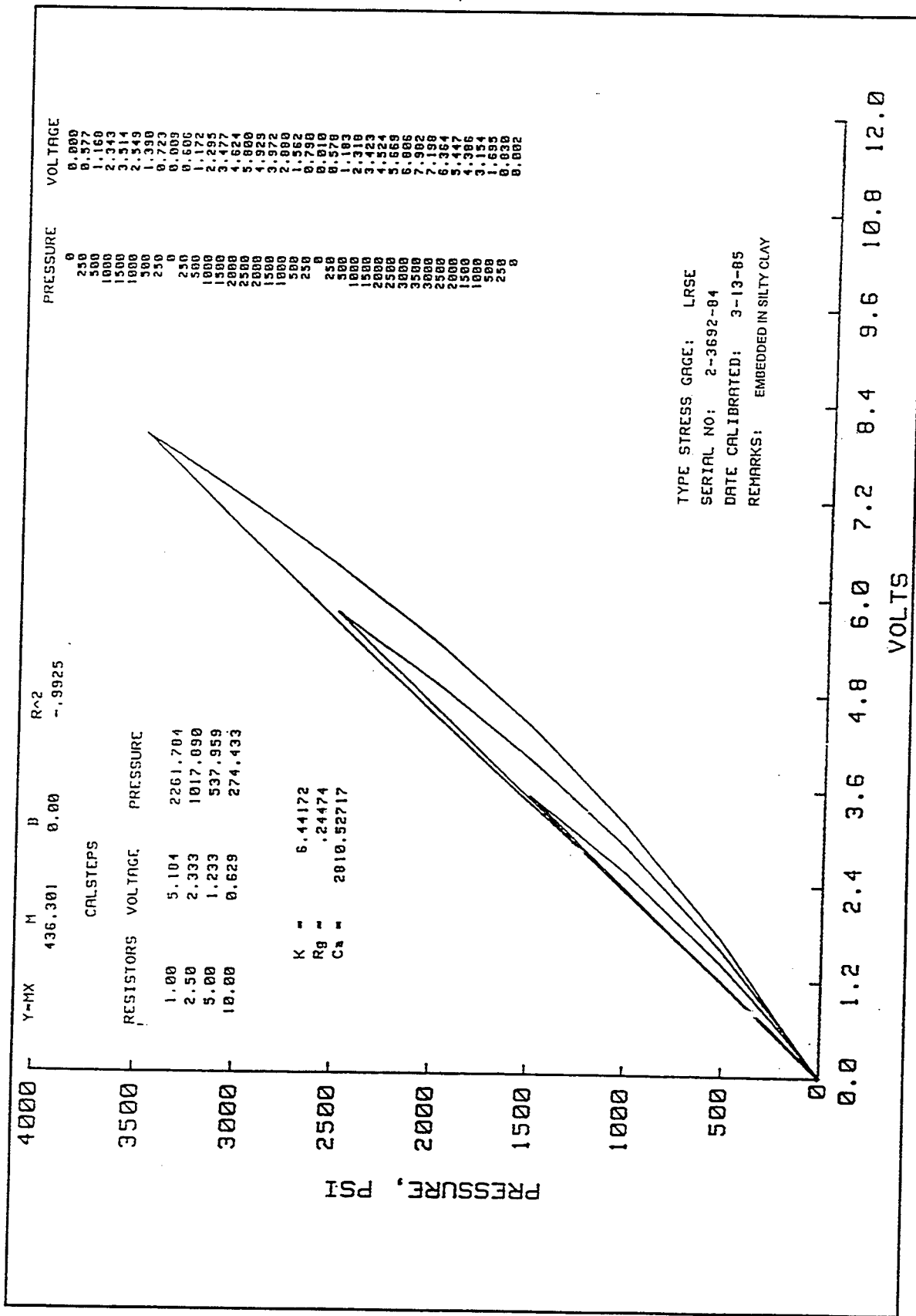


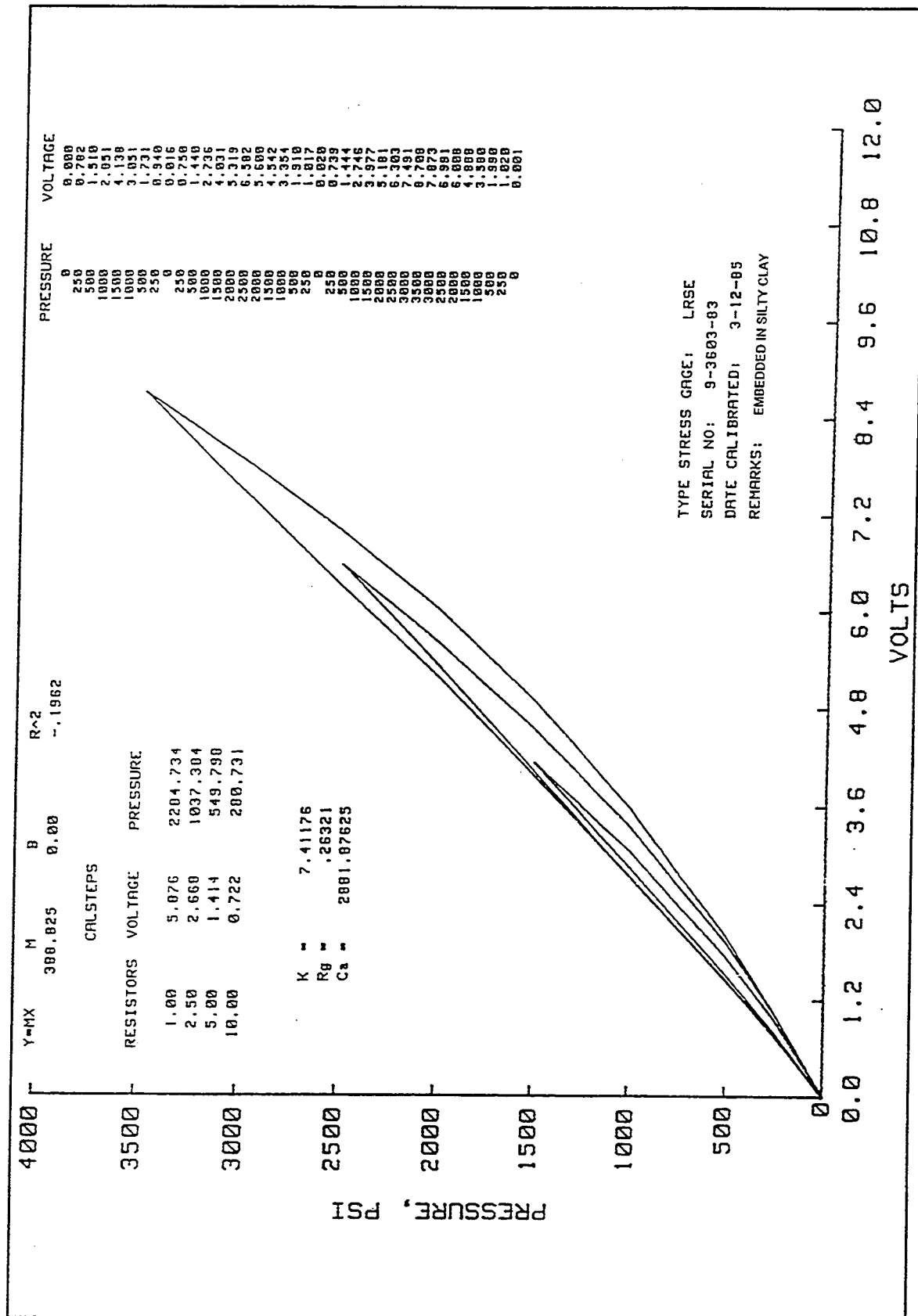


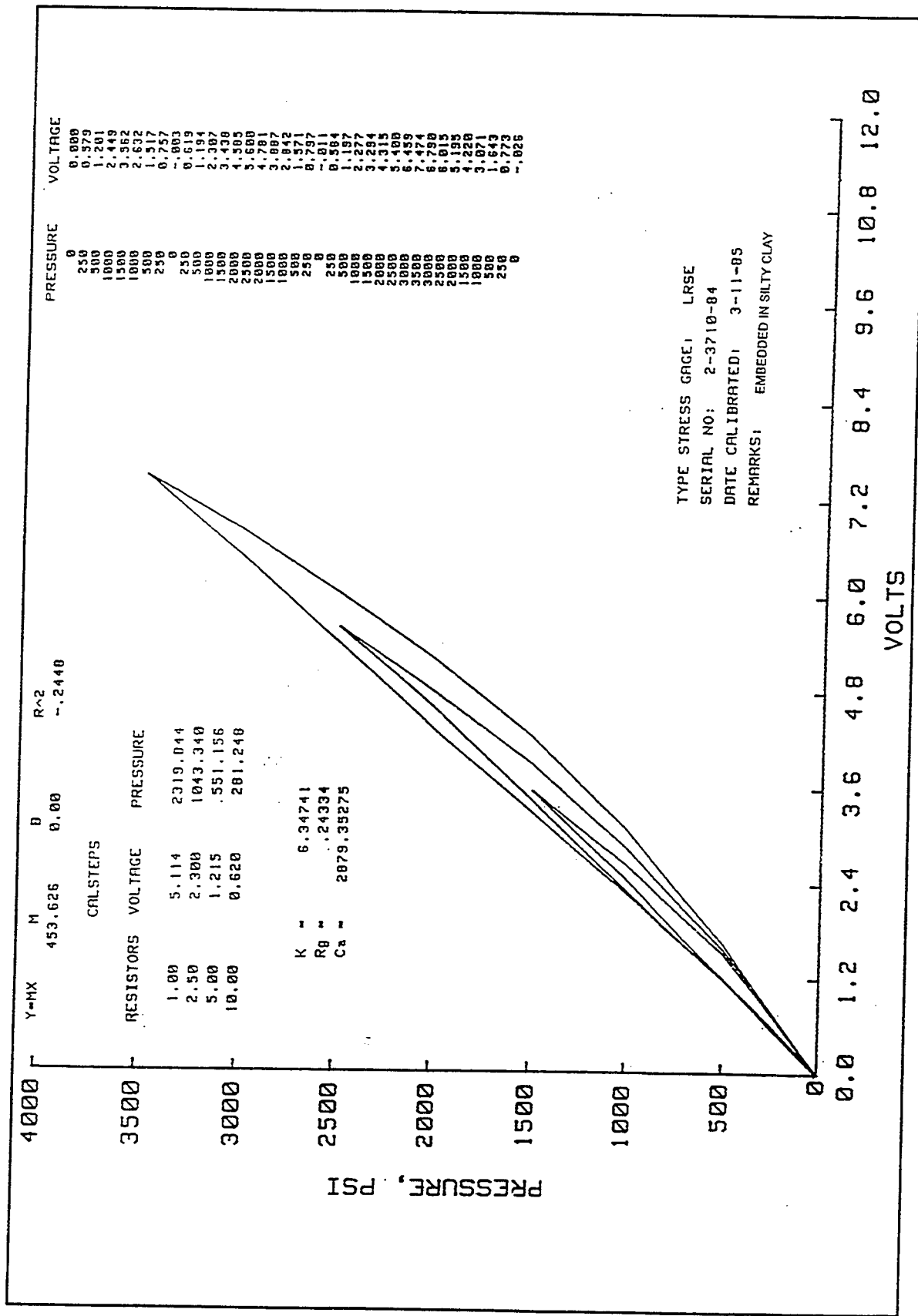


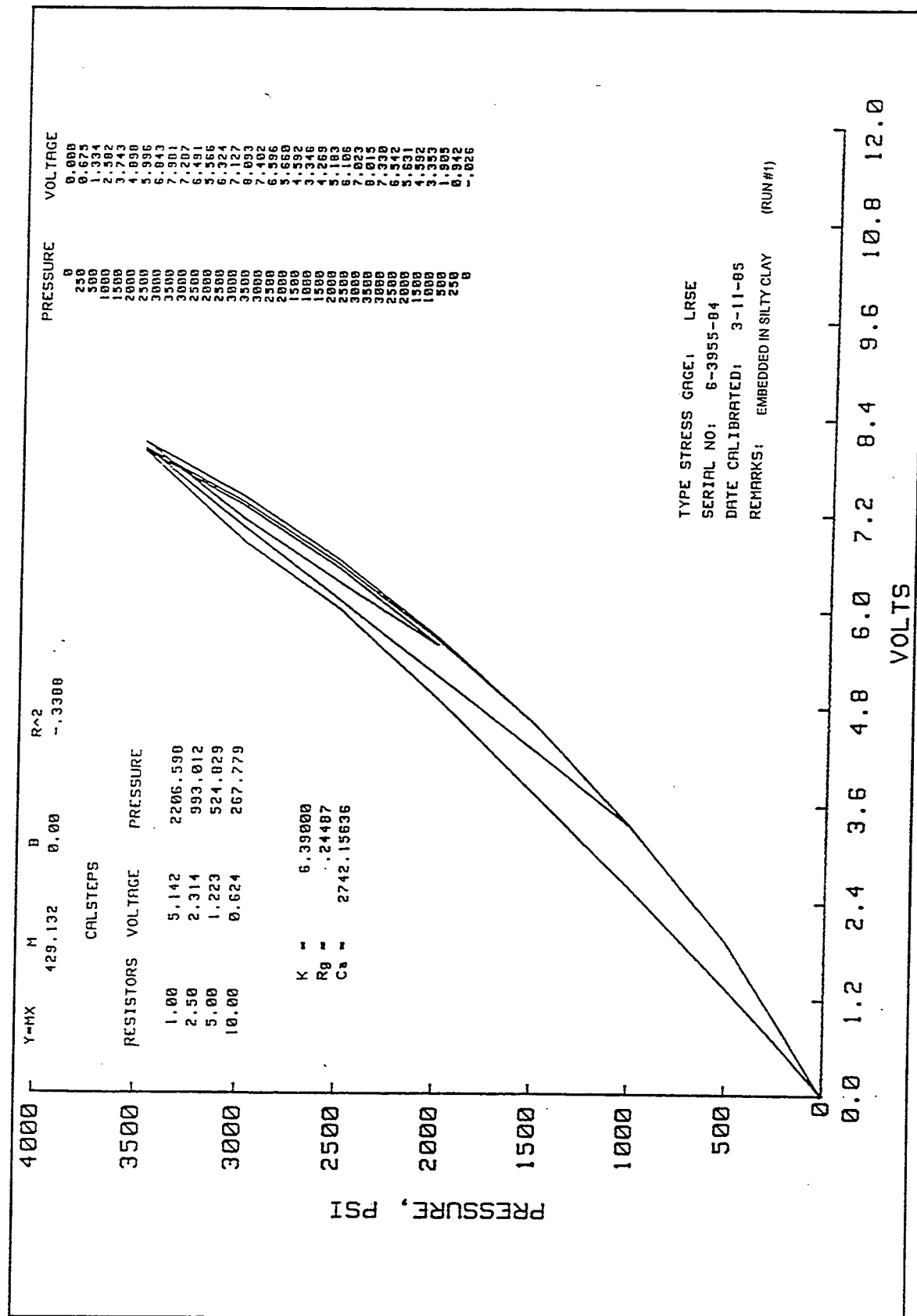


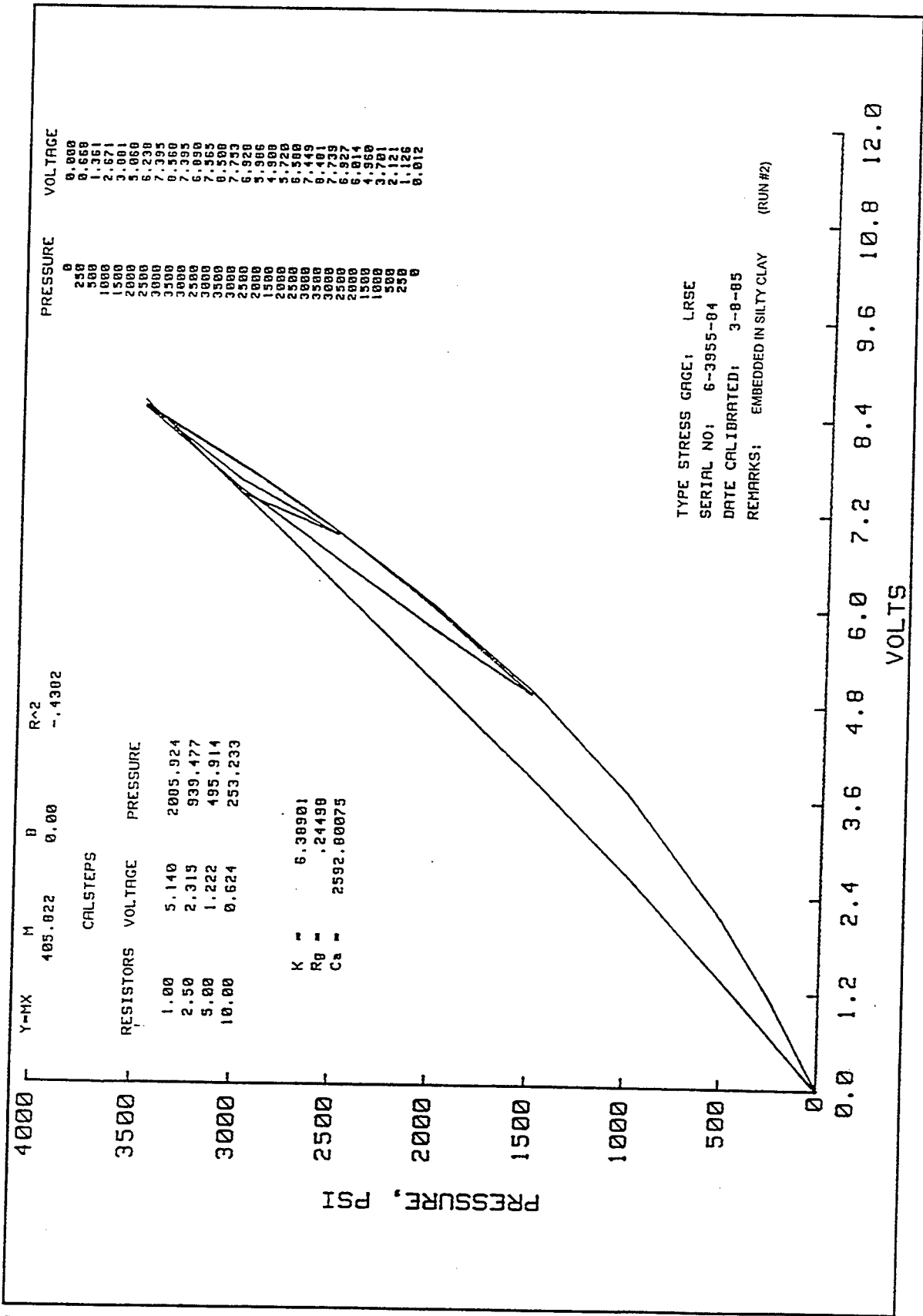






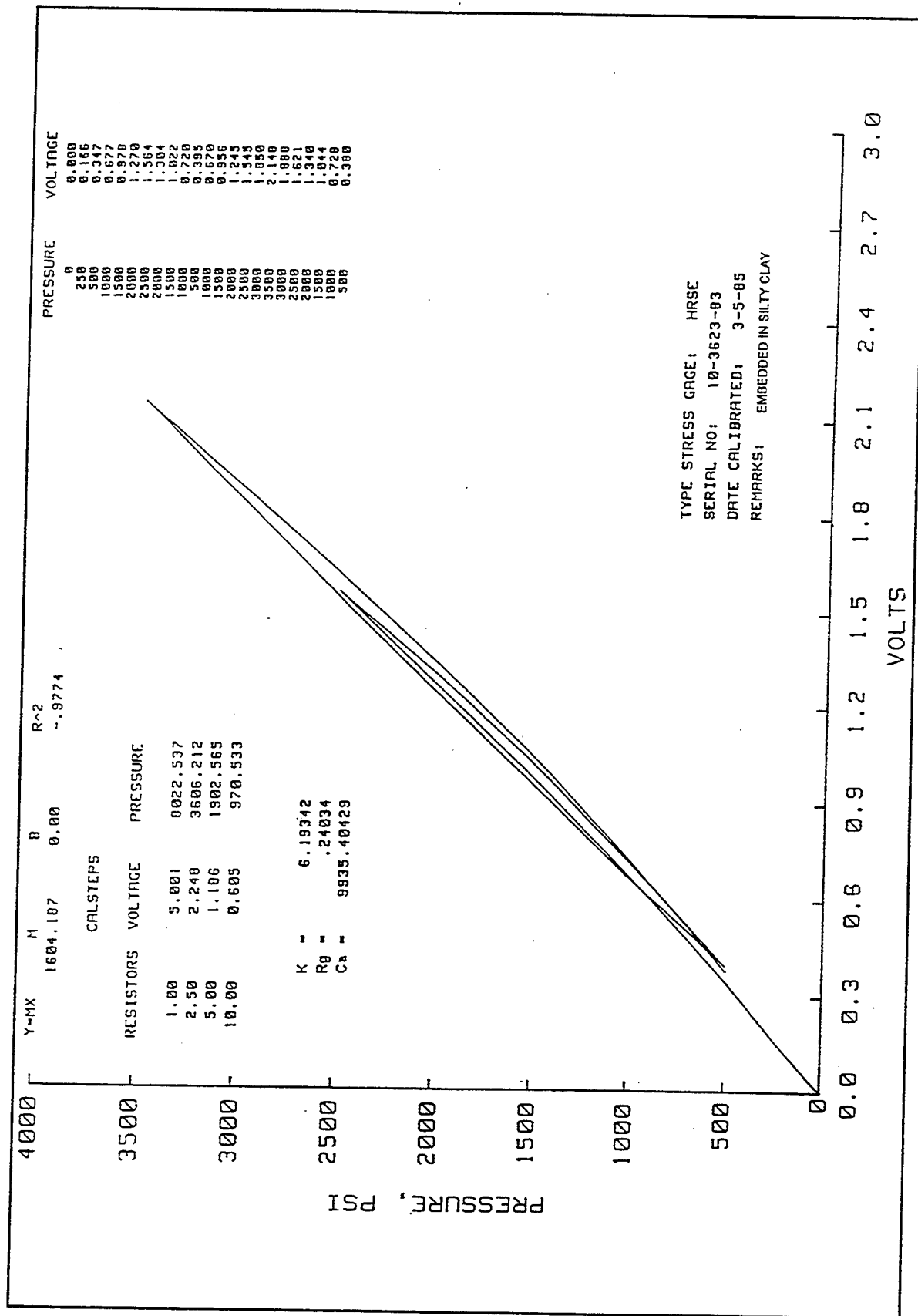


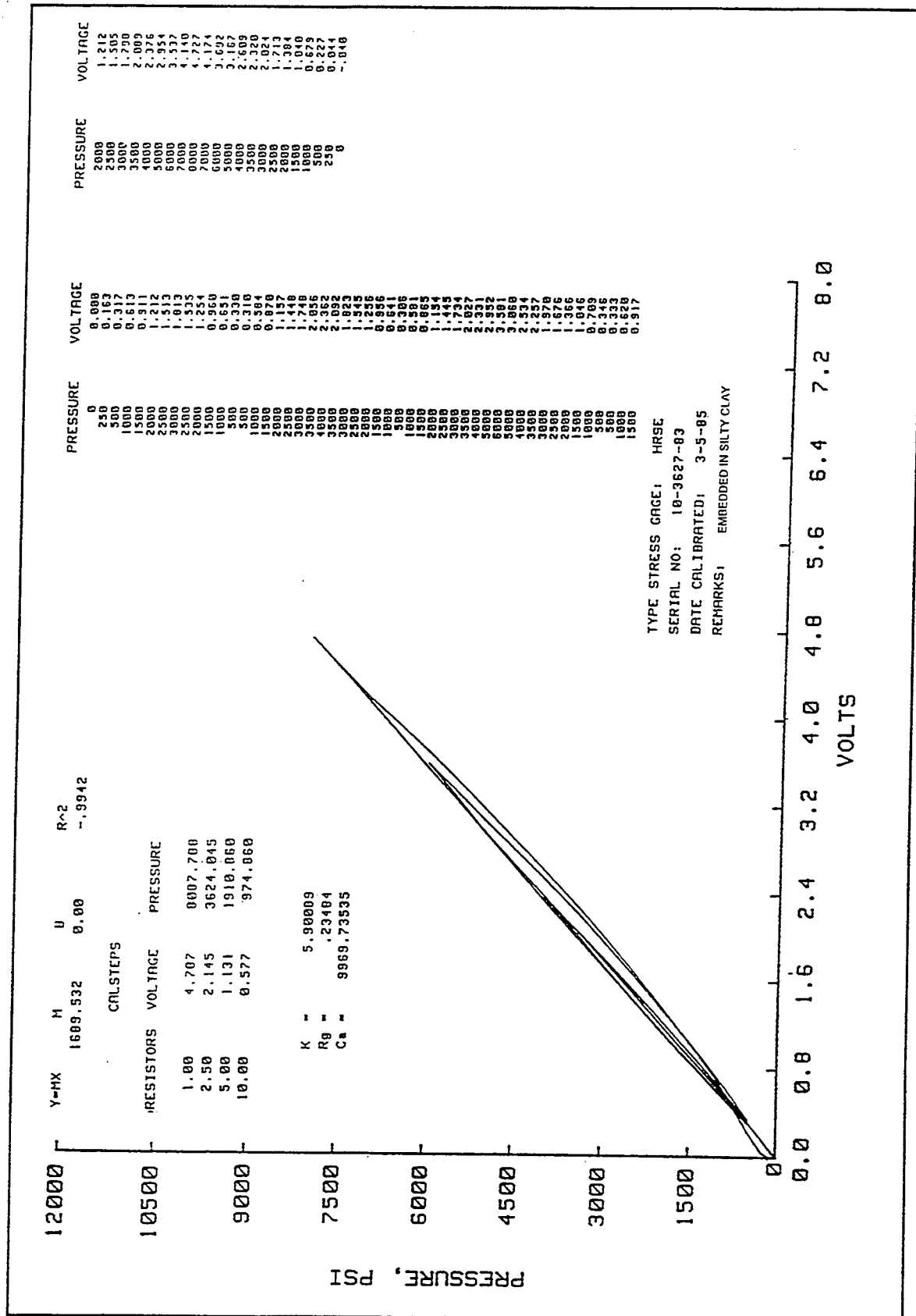


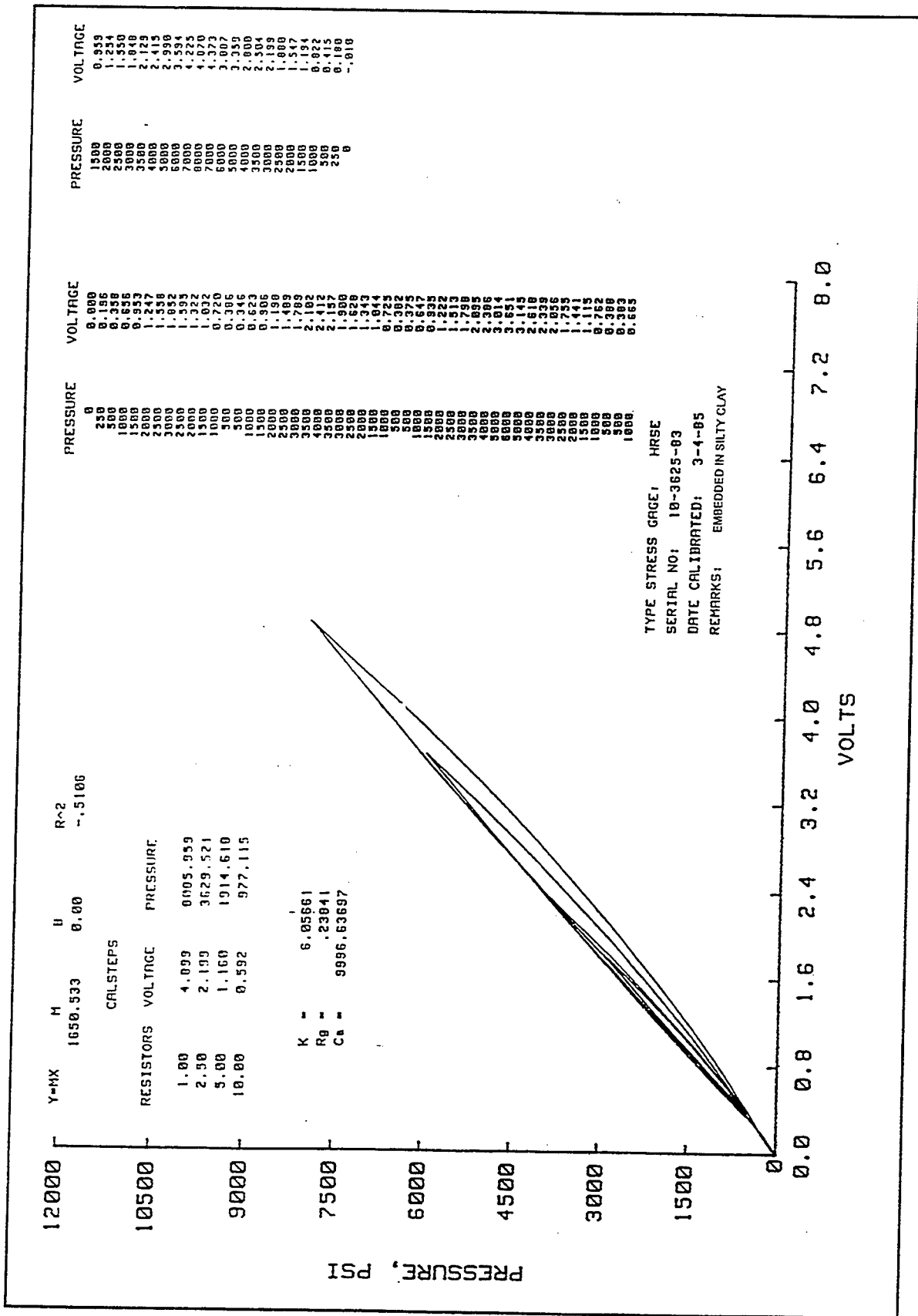


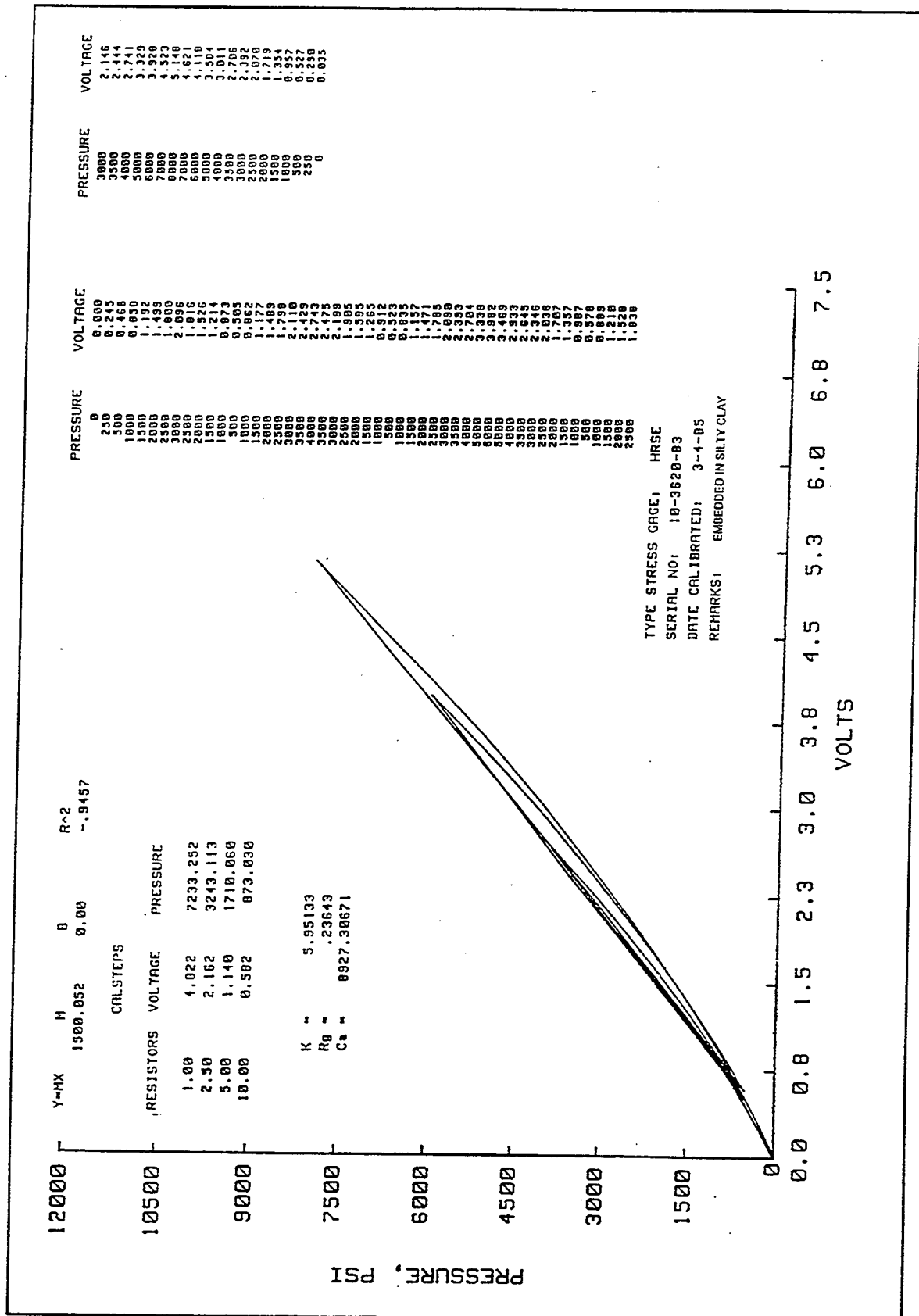


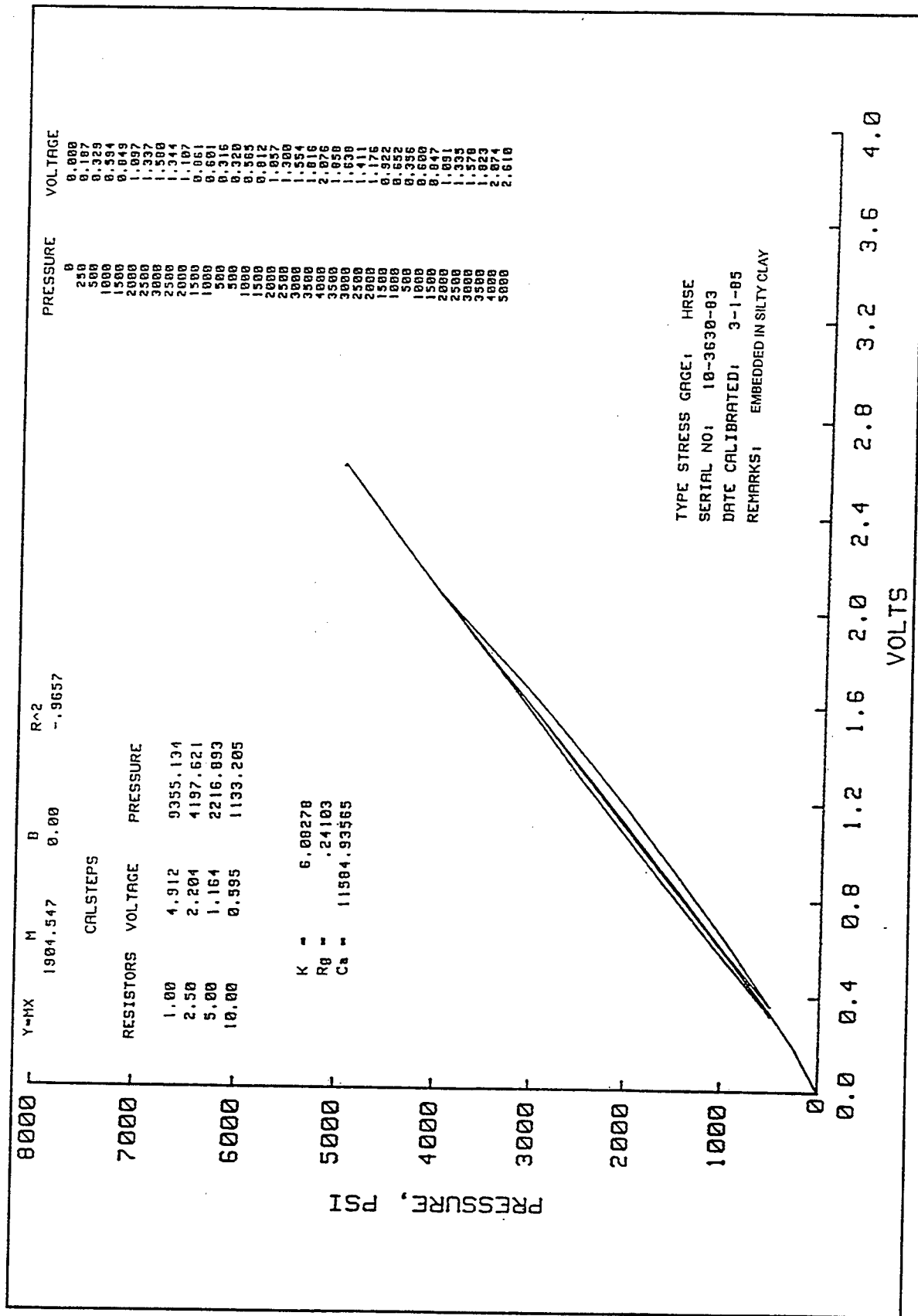


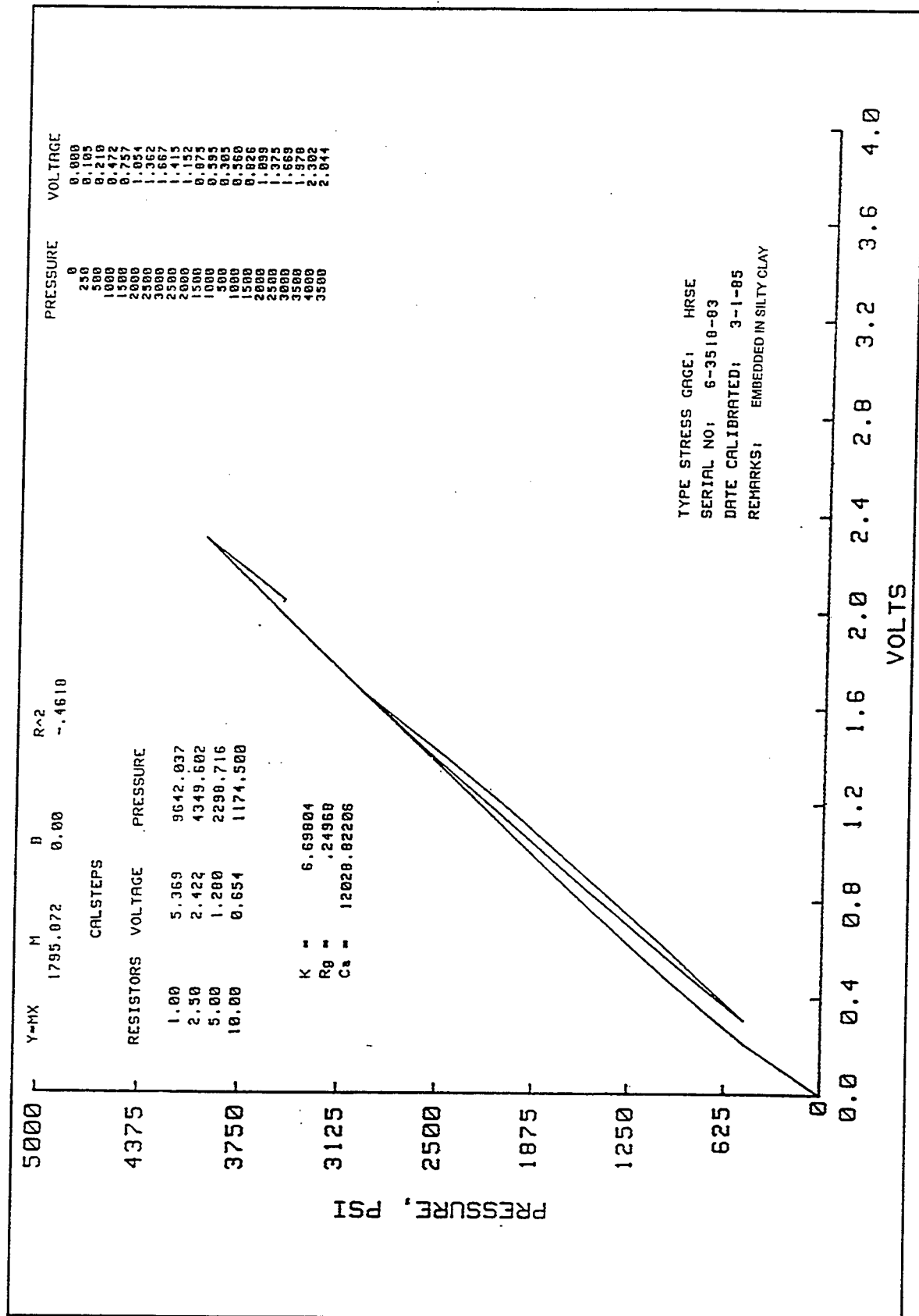


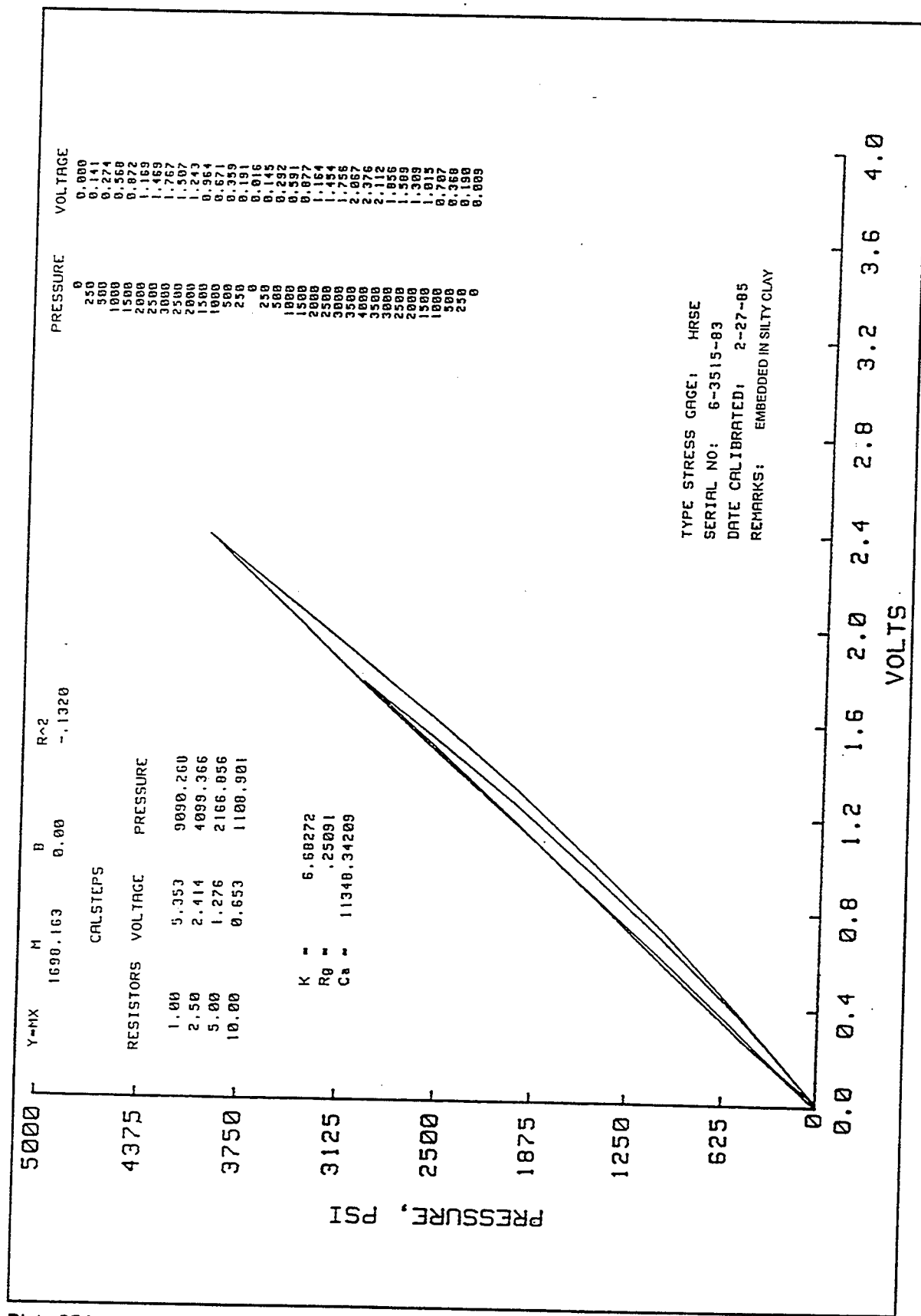


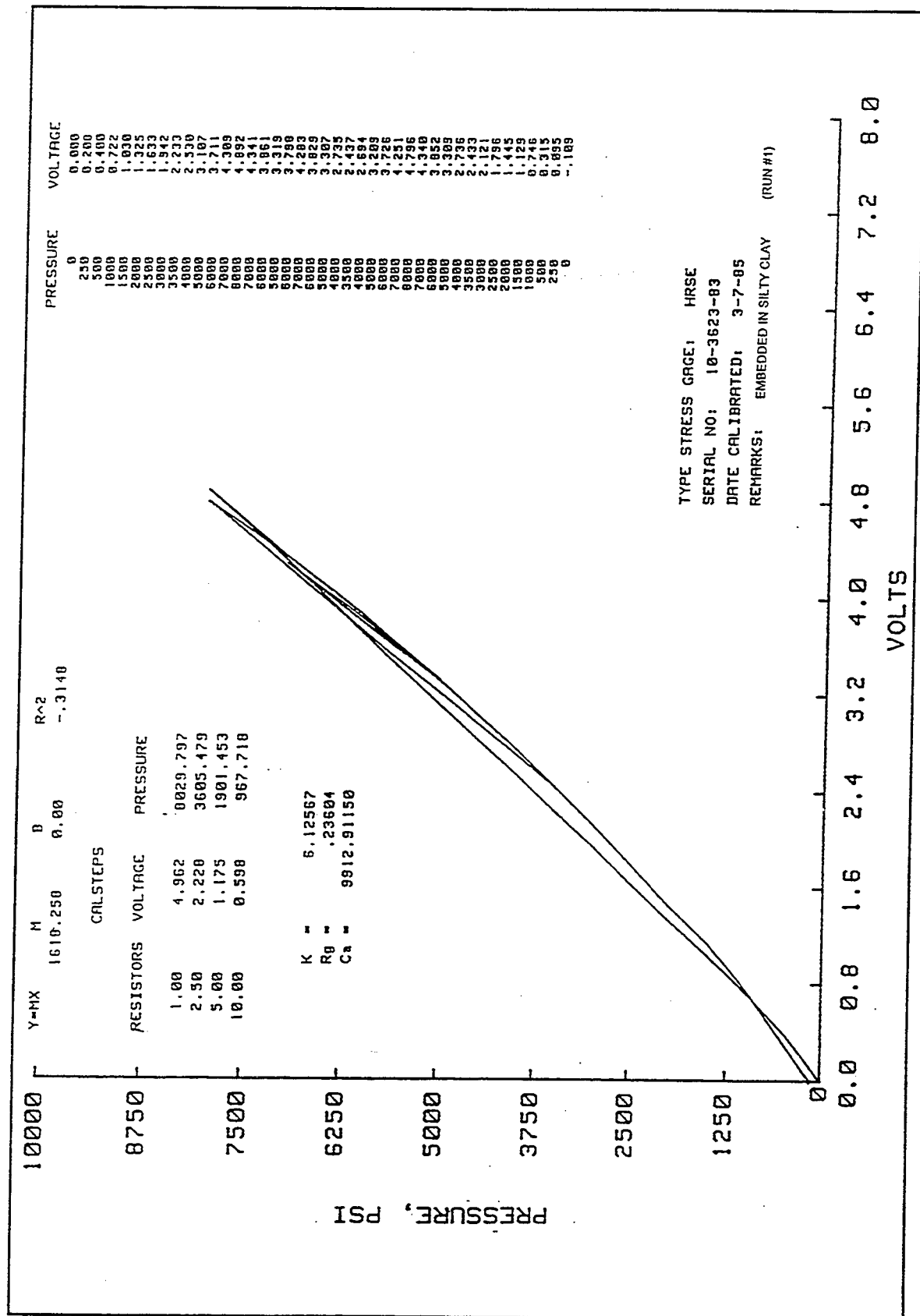




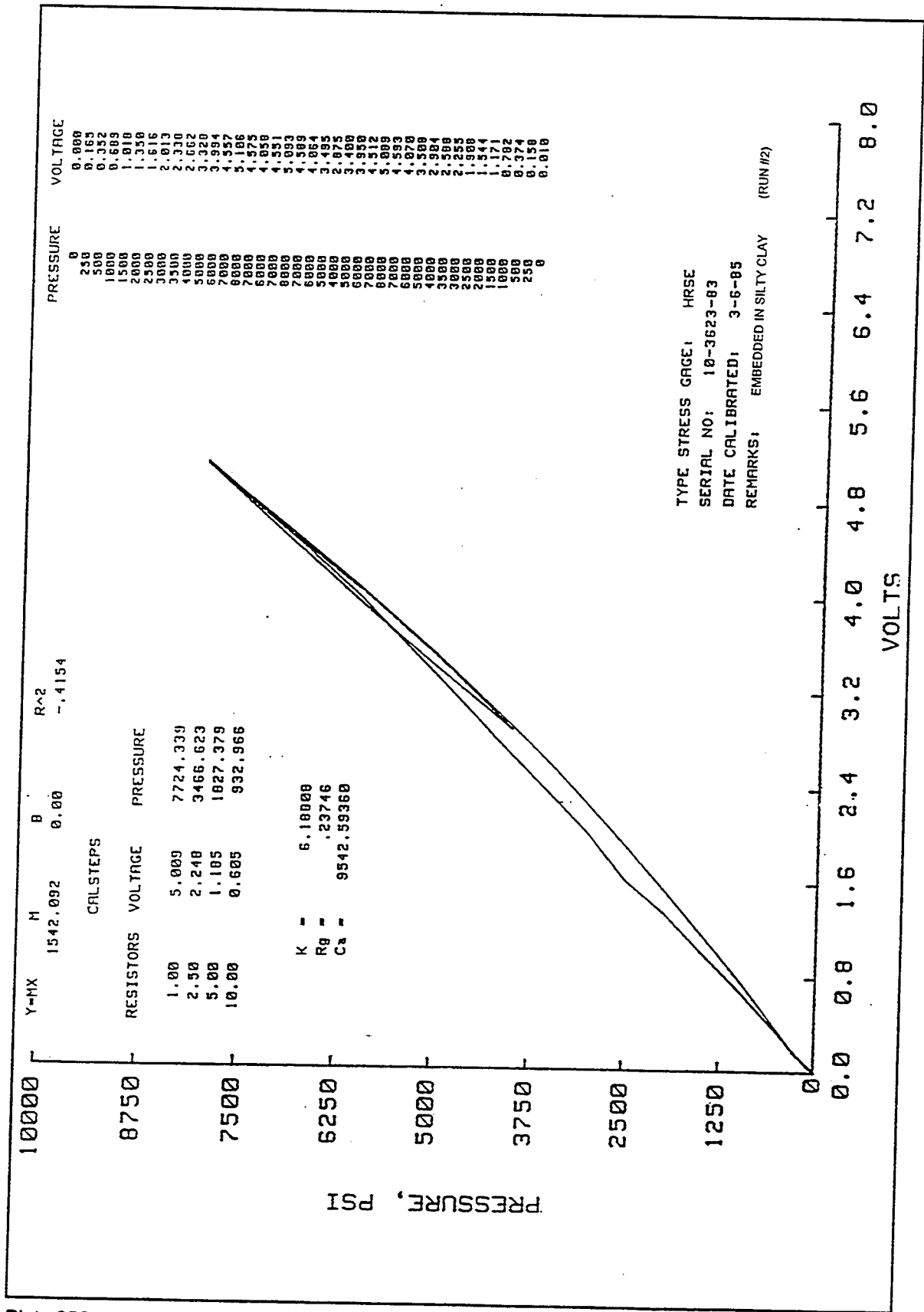


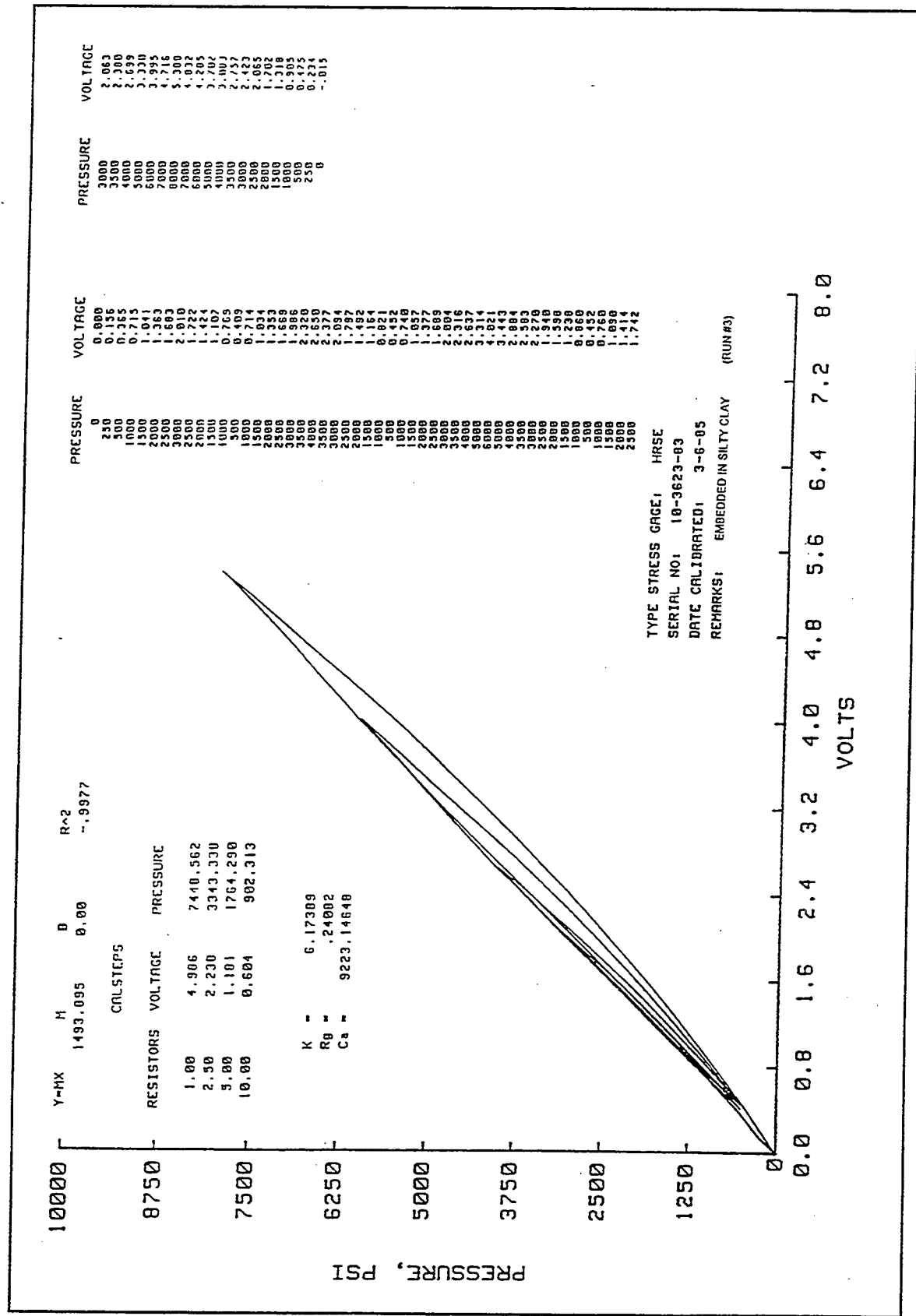




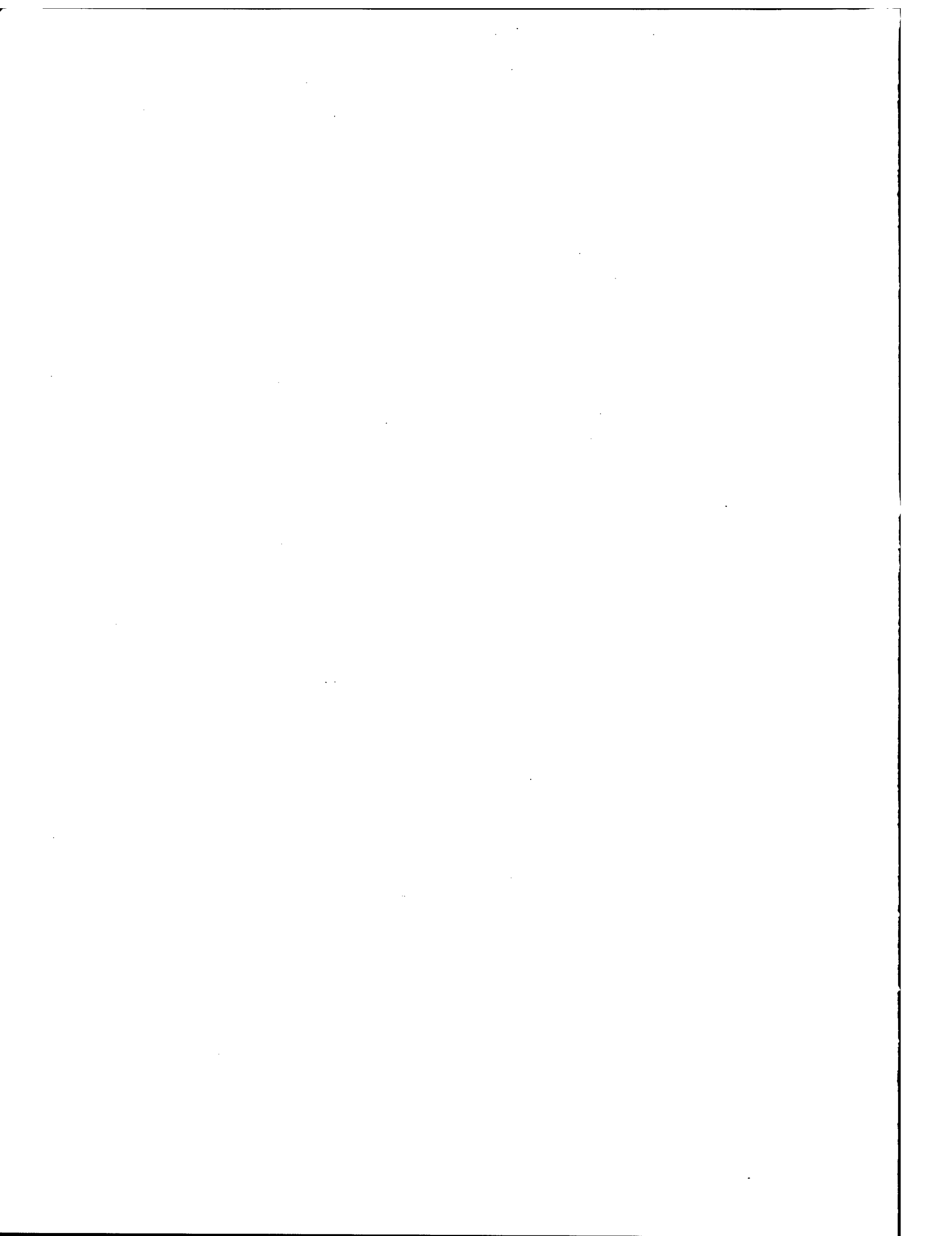








PRESSURE	VOLTAGE	PRESSURE	VOLTAGE
0	0.000	0	0.000
250	0.136	250	0.136
500	0.271	500	0.271
1000	0.542	1000	0.542
1500	0.813	1500	0.813
2000	1.084	2000	1.084
2500	1.355	2500	1.355
3000	1.626	3000	1.626
3500	1.897	3500	1.897
4000	2.168	4000	2.168
4500	2.439	4500	2.439
5000	2.710	5000	2.710
5500	2.981	5500	2.981
6000	3.252	6000	3.252
6500	3.523	6500	3.523
7000	3.794	7000	3.794
7500	4.065	7500	4.065
8000	4.336	8000	4.336
8500	4.607	8500	4.607
9000	4.878	9000	4.878
9500	5.149	9500	5.149
10000	5.420	10000	5.420
10500	5.691	10500	5.691
11000	5.962	11000	5.962
11500	6.233	11500	6.233
12000	6.504	12000	6.504
12500	6.775	12500	6.775
13000	7.046	13000	7.046
13500	7.317	13500	7.317
14000	7.588	14000	7.588
14500	7.859	14500	7.859
15000	8.130	15000	8.130
15500	8.401	15500	8.401
16000	8.672	16000	8.672
16500	8.943	16500	8.943
17000	9.214	17000	9.214
17500	9.485	17500	9.485
18000	9.756	18000	9.756
18500	10.027	18500	10.027
19000	10.298	19000	10.298
19500	10.569	19500	10.569
20000	10.840	20000	10.840
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21500	11.653	21500	11.653
22000	11.924	22000	11.924
22500	12.195	22500	12.195
23000	12.466	23000	12.466
23500	12.737	23500	12.737
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96500	52.303	96500	52.303
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97500	52.845	97500	52.845
98000	53.116	98000	53.116
98500	53.387	98500	53.387
99000	53.658	99000	53.658
99500	53.929	99500	53.929
100000	54.200	100000	54.200



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**REPORT DOCUMENTATION PAGE**Form Approved  
OMB No. 0704-0188

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<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> November 1997	<b>3. REPORT TYPE AND DATES COVERED</b> Final report	
<b>4. TITLE AND SUBTITLE</b> Soil-Embedded and Oil-Immersed Soil Stress Gage Calibration Tests			<b>5. FUNDING NUMBERS</b>	
<b>6. AUTHOR(S)</b> Walton C. Dickson, Jon E. Windham				
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> U.S. Army Engineer Waterways Experiment Station 3909 Halls Ferry Road Vicksburg, MS 39180-6199			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> Technical Report SL-97-13	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Defense Special Weapons Agency 6801 Telegraph Road Alexandria, VA 22310-3398			<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>	
<b>11. SUPPLEMENTARY NOTES</b> Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.			<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT (Maximum 200 words)</b> <p>Soil stress measurements are used to determine or deduce many aspects of high-explosive (HE) tests; hence, accurate calibrations of soil stress gages are essential to proper interpretation of test events. The soil stress gages typically used in HE tests are currently calibrated hydrostatically. The result of a hydrostatic is linear for both loading and unloading. But soils do not typically behave as linear elastic materials, i.e., soil stress-strain behavior calibration is usually both nonlinear and hydrostatic. A calibration technique is needed to convert the voltage output of a soil stress gage to a pressure based upon the soil backfill material in which the gage is embedded.</p> <p>Calibration tests were conducted on low-range (to 30 MPa) and high-range (to 70 MPa) diaphragm-type soil stress gages, denoted LRSE and HRSE, respectively, immersed in oil and embedded in soil. Three soil types were used: (1) flume sand, SP, (2) Yuma clayey sand, SC, and (3) Vicksburg loess (silty clay), CL. Calibration tests were conducted in which the voltage output of the gages was recorded. Stress gage calibration tests were also conducted in which the strain output from each of the four individual strain gages in the wheatstone bridge were recorded. The gages were oriented for both vertical and horizontal stress measurements, and calibration tests were conducted on the gages with and without confining rings. The soil-imbedded calibration test results may be used to process raw stress gage data from field tests more accurately than can be achieved using standard oil-immersed calibrations. The results from the strain output tests can be directly compared with the results from finite element gage-simulation calculations.</p>				
<b>14. SUBJECT TERMS</b> Flume sand High-explosive (HE field tests) HRSE gage LRSE gage			Oil-immersed calibration tests Soil-imbedded calibration tests Soil stress gage Vicksburg loess (silty clay)	<b>15. NUMBER OF PAGES</b> 322
			Yuma clayey sand	<b>16. PRICE CODE</b>
<b>17. SECURITY CLASSIFICATION OF REPORT</b> UNCLASSIFIED	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> UNCLASSIFIED	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b>	<b>20. LIMITATION OF ABSTRACT</b>	